TAMPEREEN TEKNILLINEN YLIOPISTO
TAMPERE UNIVERSITY OF TECHNOLOGY

IIRO KULTA

IMPLEMENTING TAKT PLANNING IN STRUCTURAL DESIGN

Master's Thesis

Examiner: Professor Arto Saari
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ABSTRACT

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This Master's Thesis covers how takt planning has been used in manufacturing and construction production, and how it could be applied to structural design. The objective of the study is to develop a proposal for a concept where takt planning is implemented in the target company's structural design processes and other lines of business, with the help of a literature survey, interviews, and workshops. Takt is based on lean principles and it has been successfully used as a production management and control method in several construction projects around the world. Takt has pointed out to be extremely useful in projects with high level of repetitiveness. Structural design, however, is iterative by nature, thus it differs from construction production in many ways. Unlike construction production, design is not a straightforward process and the focus is rather on making the information flow. This requires broad understanding of the project and constant collaboration within the major project participants. At an operational level, the problems in design will typically result in various harmful consequences. Catenating construction project's design and production as separate sequential phases may cause non-ideal solutions, poor feasibility of drawings, high level of unnecessary adjustment work, and absence of continuous improvements. Thus, optimizing the design processes to the utmost should not be the most important goal when takt planning is implemented in structural design. More important is good planning and management of own work, i.e. scheduling and resourcing of the commission, daily internal management, and required adjustment mechanisms to achieve the goals. The study implies that implementing takt planning in structural design, or in any other design process, is possible yet challenging. If the owner of the project decides to utilize takt planning at an early stage of the project, the decision will work as a prerequisite for many other decisions, contracts, and working methods to come. This means that comprehensive construction management commissions enable effective implementation of takt planning in both construction production and design. The implementation should not be done unconditionally, but rather by means of well-managed prerequisite demands, pull from the construction production, and project-pulled systems stemming from customer demands. Thus, right now the most essential goal is to enhance organizations to comprehensively understand the benefits of the lean philosophy and takt planning. Due to the limitations of time and scope reserved for the Thesis, the author developed and reported only one way to utilize and implement takt planning in structural design. To get the best results out of the target company's Lean Development Project, a greater number of potential solutions should be developed. In addition, future research should be conducted about construction projects' prerequisite management, and the construction industry's shift from the product perspective to the process perspective.

TIIVISTELMÄ

IIRO KULTA: Tahtisuunnittelun käyttöönotto rakennesuunnitteluprosessissa
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Tässä diplomityössä käsitellään tapoja, miten tahtisuunnittelua on käytetty valmistavassa teollisuudessa sekä rakennustuotannossa, ja miten sitä voitaisiin soveltaa rakennesuunnitteluun. Tutkimuksen tavoitteena on luoda kirjallisuusselvityksen, haastattelujen ja työpajojen avulla kehitysehdotus tahtisuunnittelun käyttöönotosta kohdeyrityksen rakennesuunnitteluprosesseissa ja muilla toimialoilla. Tahti perustuu lean-periaatteisiin ja sitä on käytetty menestyksekkäästi tuotannonohjausmenetelmänä useissa rakennushankkeissa ympäri maailmaa. Tahti on osoittautunut erityisen hyödylliseksi paljon toistuvuutta sisältävissä hankkeissa. Rakennesuunnittelu on kuitenkin luonteeltaan iteratiivista ja poikkeaa näin ollen rakennustuotannosta monin tavoin. Toisin kuin rakennustuotanto, suunnitteluprosessi ei ole suoraviivainen, ja siinä keskitytään pikemminkin saamaan informaatio virtaamaan. Tämä edellyttää laajaa ymmärrystä hankkeesta sekä alituista yhteistyötä tärkeimpien hankeosapuolten välillä. Ongelmat suunnittelussa johtavat tyypillisesti vahingollisiin seurauksiin operatiivisella tasolla. Suunnittelun ja tuotannon ketjuttaminen erillisiksi rakennushankkeen vaiheiksi voi johtaa epäideaaleihin ratkaisuihin, vaikeasti toteutettaviin suunnitelmiin, suureen muutostyötarpeeseen sekä jatkuvien parannusten puutokseen. Näin ollen suunnitteluprosessin äärimmäisen optimoinnin ei tulisi olla tärkein tavoite implementoitaessa tahtia rakennesuunnitteluun. Oleellisempaa on oman työn hyvä suunnittelu ja johtaminen eli toimeksiannon aikataulutus ja resursointi, sisäinen päivittäisjohtaminen sekä tavoitteiden saavuttamisen edellyttämät korjaavat toimenpiteet. Tutkimus antaa viitteitä siitä, että tahtisuunnittelun käyttöönotto rakennesuunnittelussa, tai missä tahansa muussa suunnitteluprosessissa, on mahdollista, mutta haastavaa. Mikäli rakennushankkeeseen ryhtyvä päättää jo hankkeen alkuvaiheessa hyödyntää tahtisuunnittelua, tulee kyseinen päätös toimimaan perusedellytyksenä monille tuleville päätöksille, sopimuksille ja työmenetelmille. Näin ollen kokonaisvaltaiset rakennuttamis- ja projektinjohtotoimeksiannot mahdollistavat tahtisuunnittelun tehokkaan käytön sekä rakennustuotannossa että -suunnittelussa. Implementointia ei kuitenkaan tule tehdä ehdoitta, vaan ennemminkin laadukkaan lähtötietojen hallinnan, rakennustuotannosta kumpuavan imuohjauksen sekä asiakkaan tarpeisiin perustuvien projektikäytäntöjen avulla. Tällä hetkellä olennaisin tavoite onkin kohentaa ja kannustaa organisaatioita ymmärtämään lean-filosofian ja tahtisuunnittelun hyödyt laajamittaisesti. Tutkimukselle varattujen aika- ja laajuustavoitteiden rajoittamana tutkija kehitti ja raportoi ainoastaan yhden tavan tahtisuunnittelun hyödyntämiseksi ja implementoimiseksi rakennesuunnittelussa. Jotta kohdeyrityksen Lean-kehitysprojektista saataisiin aikaiseksi parhaat mahdolliset tulokset, tulisi potentiaalisia ratkaisuja kehittää enemmän. Jatkotutkimusta kannattaisi lisäksi kohdistaa lähtötietojen ja lähtötietovaatimusten hallintaan rakennushankkeissa sekä rakennusteollisuuden siirtymiseen tuotenäkökulmasta prosessinäkökulmaan.

PREFACE

This Master's Thesis has been written to fulfill the graduation requirements of the Major in Construction Production at the Tampere University of Technology (TUT). I conducted the research between January and July 2018.

The research was challenging and the expectations were high. However, I am confident that my consistent and comprehensive research work has allowed me to answer the research questions, and thus, meet the expectations. The research project was a part of the AINS Group's Lean Development Project in which I was keen on giving my own contribution. This project has strengthened my interest in lean construction and lean design, especially in takt planning and takt control. Hence, I am more than willing to use my findings in the future to continue developing the concept I created in this project.

I would like to thank AINS Group for an interesting and remarkable topic. I would also like to thank everyone who have actively supported me during this project; Jaakko Jauhiainen and Arto Saari for excellent and flexible guidance, Janosch Dlouhy and Marco Binninger for being great hosts and mentors during and after the study trip in Germany, and Olli Seppänen for arranging the study trip and enabling me to join the Visio 2030 project team.

I would also like to thank my beloved wife Lilli for supporting me in everything I have done, encouraging me to reach the stars, and motivating me to get outstanding and rewarding results in both my professional and personal life. Her presence has literally been worth its weight in gold.

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Iiro Kulta

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1. INTRODUCTION

Takt is a lean manufacturing concept that aims to ensure that the customer demand rate is met. (Seppänen 2014) This is done by using capacity buffers and clearly defined handoffs between different trades to achieve a continuous process flow where the predictability of the process performance is high. (Tommelein 2017) Takt has been applied and used successfully in several construction projects around the world and it has pointed out to be extremely useful method in projects where construction tasks are significantly repetitive, e.g. highways, pipelines, high-rise buildings, and ship refurbishments. However, recent experiments and case studies have shown that takt can also be applied to projects that do not have a high level of repetitiveness. These experiments support prior conclusions that implementing takt planning in construction project is both feasible and beneficial. (Linnik et al. 2013)

The approaches and perspectives of takt implementation and conceptualizations differ from each other in different parts of the world. (Binninger et al. 2017a) Differences have been discovered even when takt approaches have been applied in the same geographic regions. This Masters' Thesis overviews the general characteristics and approaches of takt planning, and then takes a deeper focus on the German takt approach developed at the Karlsruhe Institute of Technology, called Takt Planning and Takt Control (TPTC).

This Master's Thesis is part of the target company's broad Lean Development Project. For this reason, the Master's Thesis is considered as a development project which is composed of two parts; (a) the development project itself designed and conducted by the author, and (b) the project reporting and proposals for further actions. The purpose of the Thesis is to study how takt planning has been used in manufacturing and construction production, and based on the findings, develop a first version of the concept where takt planning is implemented in the target company's structural design process and other lines of business. To achieve this, one main research question was set. The main research question can be divided into three sub-questions as follows:

- How takt planning could be implemented in structural design?
    a. In which parts of the structural design process takt planning could be used?
    b. What benefits and advantages could be achieved by takting a structural design process?
    c. What problems and challenges there are in implementing takt planning in structural design process?

Before finding answers to the main and sub-questions, there are three preliminary questions to be answered first. The preliminary questions are:

1. What is takt, what is it based on, and how it has been used in other industries?
2. How takt has been used in construction industry, particularly, in construction production?
3. How takt-based methods used in construction and other industries could be applied into concrete and usable methods and tools for structural design?

A literature survey focuses mainly on the preliminary questions and it is reported in chapters 2-5. Chapter 2 consists of a synopsis of the generic theoretical lean principles and introduces certain generic lean methods. The first part of chapter 2 is based on the Toyota Production System. (Liker 2004) The second part introduces takt as a lean method.

Other parts of the Master's Thesis are following the guidelines of a framework called Double Diamond model. The Double Diamond model is developed for creative processes where "a number of possible ideas are created (divergent thinking) before refining and narrowing down to the best idea (convergent thinking)." (Design Council) This approach can be illustrated by the shape of a single diamond. In the Double Diamond model, however, this creative process is done twice – First to confirm the problem definition and then to create a solution. The Double Diamond model and its general features are illustrated in figure 1.

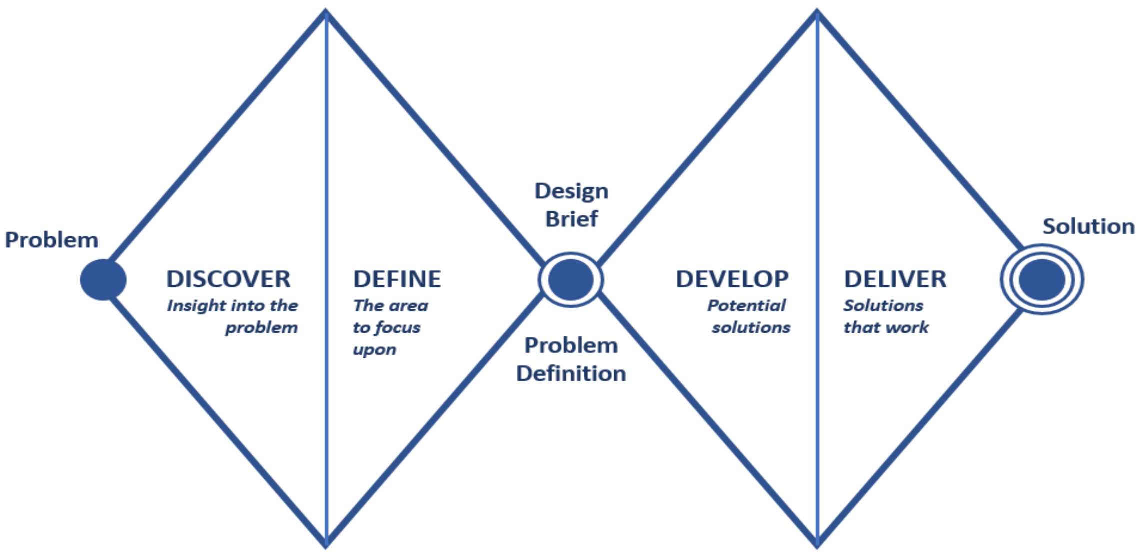

Figure 1. *The Double Diamond model (Design Council)*

According to the Design Council, one of the most fundamental mistakes in creative designing and developing projects is to neglect the first diamond and end up solving the wrong problem. The target in this Master's Thesis was to avoid that from happening by covering both phases of the first diamond thoroughly before defining the problem and developing possible solutions and answers to the main research question and its three sub-questions.

The Double Diamond model is divided into four distinct phases, which are discovering, defining, developing, and delivering. In order to discover which ideas are the best, creative design process should be iterative by nature. In other words, ideas should be first developed, then tested and finally refined. (Design Council) In order to avoid the Master's Thesis becoming too broad, the Thesis was narrowed down to focus and cover only the first three quarters of the Double Diamond model.

The discovering phase of the Double Diamond model covers the start of a project. The objective is to "look at the world in a fresh way, notice new things and gather insights." (Design Council) In this Master's Thesis, the discovering phase was done by studying literature and other theoretical knowledge of the lean principles, continuous flow, and takt planning in the context of the construction industry. The theoretical foundation for the discovering phase is reported in chapter 3.

In addition to the knowledge gathered from the literature, one important part of the Master's Thesis was a study trip to Germany to acquaint the author with two German construction companies and their ways to implement takt planning and takt control in their own construction projects. The purpose of the study trip was to get a deep and more comprehensive understanding about the doctrine developed and used in Germany, and see real-life examples of construction projects where takt planning and takt control have been implemented. Chapter 4 is mostly based on the scientific papers that describe the takt integration approach developed in the Karlsruhe Institute of Technology. The theoretical knowledge from the literature is complemented with empiric observations made, and private discussions had during the study trip in Germany. The complementary knowledge and real-life projects facilitated the understanding of the scientific papers written by researchers from the KIT.

The second quarter of the Double Diamond model is the definition phase. The first objective of this phase is to make sense of all possibilities and ideas that were identified during the discovering phase, and narrow them down until only the best ones are left. Second objective is to develop a clear and creative overview to frame the project's main challenge. (Design Council) In order to establish the fundamental problem-solution dilemma, the defining phase was conducted by puzzling potential solutions and answers to the following questions:

- Which things, insights, methods, etc. identified during the discovering phase matter the most from the target company's point of view?
- Which things, insights, methods, etc. identified during the discovering phase are feasible at target company?
- What would it mean for the target company if one or more of these possibilities would be further developed, tested, and launched?

The defining phase was conducted by the author in two stages. In the first stage, the author himself analyzed and estimated potential ways of how lean principles and especially takt planning could be implemented in structural design and for target company's other lines of business. This was based on the insights and findings from the literature survey related to flow in design processes and the empiric observations and notes from the study trip in Germany. The first stage of the defining phase is reported in chapter 5.

The second stage was composed of two workshops with target company's executives. The objective of these two workshops was to introduce the principles of takt planning and discuss and discover how, and in which format, takt planning could be applied into usable concepts at the target company.

The interlinking point between the first and the second diamond represents a design brief and actual problem definition. Once the insights and ideas are gathered, analyzed, discussed, and narrowed down, it is time to develop a vision and plan to create the outcomes. (Design Council)

In order to get a vision of the ways how lean principles and takt planning will be applied to target company's projects and every day business, a third workshop was organized. The participants for this workshop were the author and two executives being in charge of managing target company's overall business and development issues. The objective of this workshop was to summarize everything that has been done, discovered, learned, and defined so far, and based on that, figure out what are the most relevant problems to tackle with lean principles and takt planning, what are the methods and tools for that, and finally, how to implement, test, and further develop them. All three workshops are reported in chapter 6.

The third quarter of the Double Diamond model represents the developing phase. This phase marks a development period for creating, prototyping, testing, and iterating the solutions and concepts that have been taken into further consideration. The aim of this phase is to create good conditions so the ideas and actions can be improved and refined.

Based on the insights from the discovering phase and results from the workshops from the definition phase, the author developed and presented an exemplary proposal for a one potential solution of how the target company could utilize lean principles and takt planning, and how the benefits could be maximized. The developing phase is reported in chapter 7.

This Master's Thesis covers only a part of the development phase. The delivery phase was entirely left outside the scope of the Thesis. This decision was made due to the limitations of time and scope planned and reserved for the Thesis. For that reason, the author only developed and reported one way to utilize and implement lean principles and takt planning in structural design and other target company's lines of business. In order to get the best results out of the target company's Lean Development Project, a greater number of potential solutions should be developed.

All findings of the Thesis are linked back to the research setting and questions in discussion in chapter 8. The purpose of the discussion is to interpret and describe the significance of the findings and compare them to the information and knowledge that was already known about the topic. New insights and understanding are explained by taking the new findings into account.

Conclusion is reported in chapter 9. Conclusion is composed of a synthesis of key points of the Thesis and recommendations for further steps and research. Since the last quarter of the Double Diamond model was not covered in the Thesis, a vision and suggestions for the future actions to fulfil all four phases are also presented in chapter 9.

2. LEAN PRINCIPLES AND TAKT

Lean is a manufacturing philosophy invented by Japanese automotive manufacturer Toyota. It is also known as Toyota Production System or TPS. The core idea and principles of TPS are mostly developed by former Toyota engineer Taiichi Ohno. (Liker 2004) Liker (2004) characterizes TPS as “the next major evolution in efficient business processes after the mass production system invented by Henry Ford.” The recognition of lean production in the 1990s launched a global transformation towards Toyota’s methods and philosophy in many industries. Terms “lean” and “lean production” were publicized in the books The Machine That Changed the World (Womack, Jones & Roos 1991) and Lean Thinking (Womack & Jones 1996). Womack and Jones (1996) describe lean manufacturing as a five-step process where the steps are

1. defining customer value,
2. defining the value stream,
3. making it flow,
4. pulling from the customer back, and
5. striving for excellence.

By their definition, a lean manufacturer should focus on creating

1. value-adding processes where the products flow without unnecessary interruptions,
2. pull systems where the preceding process depends on the subsequent process that cascade all the way back from customer demand, and
3. an organization culture where all participants from the shop floor workers up to the top executives are striving continuously to improve.

Figure 2 represents the main characteristics of the Toyota Production System.

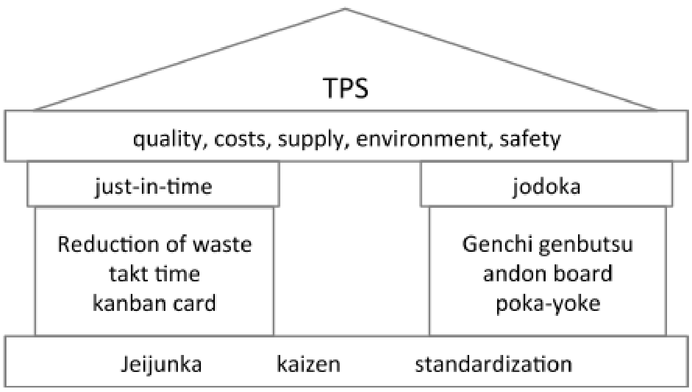

Figure 2. *The Toyota Production System (Haghsheno et al. 2016; Toyota 2010)*

The heart of the lean philosophy is eliminating non-value-adding work to achieve and maintain continuous process flow. Non-value-adding work activities are called waste. (Liker 2004) Continuous flow brings potential problems to the surface before or immediately after they emerge. (Fiallo & Howell 2012) According to Liker (2004), lean processes should be started by creating a continuous flow because that enables the implementation of many other lean tools. One tool that establishes the amount of work that must flow through a specific process in a specific time is called takt. Liker (2006) describes takt as a "straight link between customer and production system that sets the rhythm of a production system."

2.1 Lean thinking according to the Toyota Way

The Toyota Way is the fundamental way Toyota views its world and does business. Toyota Way is not the same thing as lean, even though the two are strongly connected with one another. Lean "is the most systematic and highly developed example of what the principles of the Toyota Way can accomplish." (Liker 2004) According to Jeffrey Liker's studies of Toyota, the two core pillars that support the Toyota Way are continuous improvements (kaizen) and respect for people. Continuous improvements require "an atmosphere of continuous learning and an environment that not only accepts, but actually embraces change". (Liker 2004) The only way to create such an environment is by respecting people. Toyota is doing that, for instance, by providing employment securities, giving its employees a possibility to participate in improving their jobs, and developing mutual trust between all team members.

The heart of the Toyota Way is eliminating activities that do not add any value to the customer, also known as waste. (Liker 2004). Many lean tools and principles stem from this focused behavior. Waste occurs in all types of business and manufacturing processes. Toyota has identified seven major types of waste, that are overproduction, waiting, unnecessary conveyance, over processing, excess inventory, unnecessary movements, and defects. Table 1 summarizes the main features of the seven types of waste identified by Toyota.

Table 1. *Seven types of waste identified by Toyota. (Liker 2004)*

Name of the waste	Characteristics of the waste
Overproduction	Producing items or products that are not ordered or which the client does not need. Overproduction also generates other forms of waste, such as storage costs, transportation costs, and overstaffing. Thus, it is commonly considered as the fundamental waste, and according to Toyota, it is the worst waste of all.
Waiting	Waiting means for example time spent by workers for standing around waiting for the next processing step, tool, supply, product, etc. It is also waiting if there are workers who do not have anything to do because of stock outs, processing delays, equipment downtime, capacity bottlenecks, etc.
Unnecessary transport or conveyance	Unnecessary transport consists of inefficient transport, conveying materials, products, equipment, finished goods, etc. for long distances or moving them into or out of storage or between processes.
Over processing or incorrect processing	Over processing means producing higher-quality products than what was really needed or necessary. Waste is generated from unneeded steps, inefficient time-usage, unnecessary motions, and production defects.
Excess inventory	Excess inventory causes longer lead times, obsolescence, damaged goods, unnecessary transportation, and storage costs and delays. Many times, excess inventory walks hand in hand with overproduction. Excess inventory also creates risks of hidden problems, e.g. imbalances in the production system, late deliveries from suppliers, equipment downtime, and long setup times.
Unnecessary movements	Unnecessary movement is any wasted motion that an employee is performing during the work. Examples include looking for, reaching for or stacking tools, materials, equipment, etc. In some contexts, walking can also be considered as unnecessary movement.
Defects and mistakes	Producing defective items, parts or finished goods that are not usable or require correction, repair, rework, replacements, etc. is also waste. In addition, defects often create new waste, such as wasteful handling, unnecessary inspections, and additional quality checks.

Non-value-adding time might compose a significant part of the total process time. Employees and managers are often so used to traditional ways of performing the work, that the low percentage of value-adding time becomes and stays ‘hidden’. For that reason, traditional cost savings and time reductions have focused mostly on value-adding items and the ways to improve and optimize them. Lean thinking turns this approach upside down and rather focuses on the value stream to eliminate non-value-adding items. (Liker 2004) Figure 3 illustrates the proportional share of both value-adding activities and non-value-adding activities in a transformation process that has been stretched to a point where it is almost impossible to recognize the value-adding phases anymore.

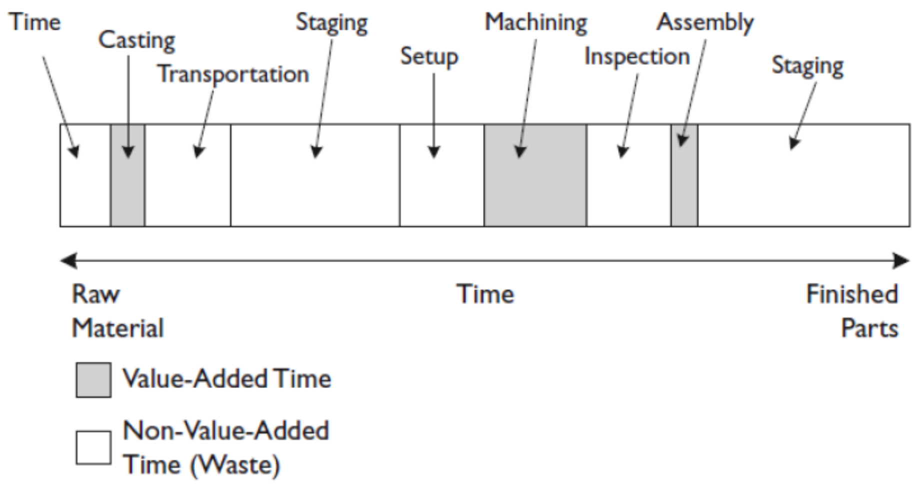

Figure 3. *Proportional share of waste in a value system. (Liker 2004)*

By means of organizational culture that encourages to continuous improvements and technical systems that support value-added flow, Toyota has achieved remarkable success in the automobile industry and turned its excellence at the operational level into a strategic weapon. (Liker 2004) The Toyota Way is composed of several individual elements, tools, and quality improvement methods such as kaizen, one-piece flow, and just-in-time. However, the most important part of the Toyota Way is to form a **transparent system** of those elements and tools, and practice it in a consistent manner to build a deeper lean-based business philosophy.

2.1.1 The 4 P model

Liker (2004) describes 14 principles that compose the Toyota Way. He divides these principles into four sections that all start with letter P. The sections are Philosophy, Process, People/Partners, and Problem Solving. (Liker 2004) Liker’s 4 P model is illustrated in figure 4.

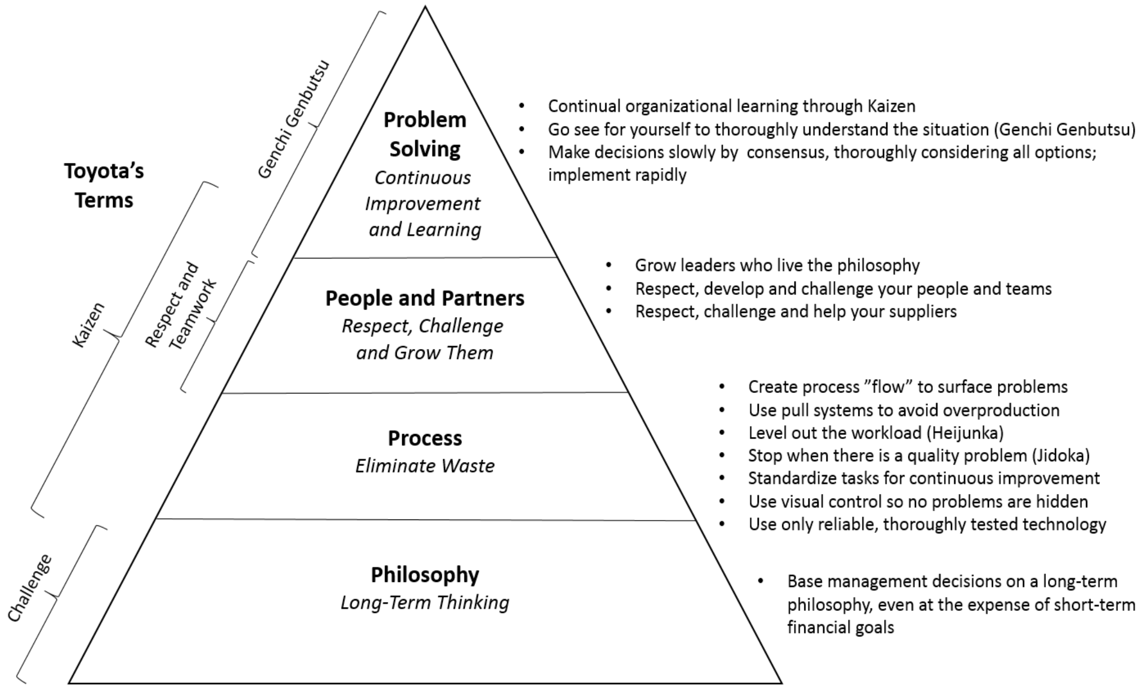

Figure 4. *The 4 P model of the Toyota Way. (Liker 2004)*

Long-term **Philosophy** focuses on adding value to both customers and society. It aims at building a learning organization that can cope with the dynamic and constantly changing environment. Long-term Philosophy is the foundation of the Toyota Way, without which continuous improvements and learning would not be possible. According to Liker (2004) "The Right **Processes** will produce the right results". This is the level most of the 'lean' companies have adapted, albeit they are usually struggling or neglecting the other three Ps. (Liker 2004) The key to achieve the best quality in a cost-effective way without sacrificing the safety, is to make the processes flow. Toyota has learned by trial and error how the processes will work with an ideal one-piece flow. The one-piece flow is a challenging process where errors can quickly raise problems that require very fast decision-making and solutions. The Toyota Way includes tools that are specifically designed to support employees' continuous improvements and development. This leads to the 4 P model's third level: "Add value to the organization by developing your **People and Partners**." The highest level of the Toyota Way is organizational learning and continuous **Problem Solving**. The learning system begins from identifying the root causes of problems and preventing them from occurring again. The learning and improvement processes continue with tough analyses, reflections, and discussions of the lessons learned whereas the best of the identified practices will be standardized. (Liker 2004)

2.1.2 The 14 principles of the Toyota Way

Principle 1. Base your management decisions on a long-term philosophy, even at the expense of short-term financial goals. This principle urges to see the big picture. Making a quality product should not be the main purpose of business. That is a requirement to achieve the true mission: generating value for the customer, society, and the economy. By a wider view of the organization's position and history, organization can be taken to the next level. Being responsible and acting with self-reliance are necessary abilities when maintaining and improving the skill-set needed for producing added value and deciding one's own fate. Good long-term philosophies will not grow up overnight so they should not be dropped overnight, even if it would be justifiable from a short-term perspective. (Liker 2004)

Principle 2. Create continuous process flow to bring problems to the surface. Continuous flow is one of the central elements of the Toyota Way. It is based on eliminating waste. The continuous flow also links materials, information, and people together enabling fast recognition of emerging problems. The key to a continuous improvements and learning is to have a flow that appears throughout the whole organization. (Liker 2004)

Principle 3. Use pull systems to avoid overproduction. Material used in the production processes should be replaced by consumption. Minimizing the unnecessary and wasteful warehousing is the core idea of just-in-time thinking. Just-in-time production process enables to deliver the right number of right products to the customers exactly when they want them. (Liker 2004)

Principle 4. Level out the workload. In Japanese, this principle is called *heijunka* which means working like a tortoise, not a hare. Eliminating waste is not enough to make lean successful. In addition, eliminating overburden to people and equipment and eliminating unevenness in the production schedule, are just as important, albeit the latter is often neglected at companies that are trying to be lean. (Liker 2004)

Principle 5. Build a culture of stopping to fix problems, to get quality right the first time. Japanese term *jidoka* is the foundation for building in quality. Developing visual systems that tell managers if equipment or process needs assistance and using modern quality assurance methods and systems that can solve surfacing problems quickly, are centerpieces of Jidoka. Getting required quality right the first time improves the productivity in a long run. (liker 2004)

Principle 6. Standardized tasks are the foundation for continuous improvement and employee empowerment. Stable and repeatable methods help to maintain predictability and regular timing and outputs of the processes. This is the foundation for flow and pull. Standardized methods also reduce many problems arising from the sharing of the tacit knowledge because when people move on, it is easier to hand off the learning to the new people. (Liker 2004)

Principle 7. Use visual control so no problems are hidden. Simple visual systems support the flow and the pull. Clearly visible indicators help to recognize whether the standard conditions are fulfilled or not. The reports should be as short as possible. Focusing too much on staring at computer screens should also be avoided because it moves worker's focus away from the actual workplace. (Liker 2004)

Principle 8. Use only reliable, thoroughly tested technology that serves your people and processes. The meaning of technology is to support people, not to replace it. New technologies can be harmful for the flow and therefore well-working process should always take precedence over untested technology. Technologies that are disrupting stability, reliability or predictability should be modified or even rejected. Only technologies that have been proven in trials and can improve flow, should be implemented quickly. (Liker 2004)

Principle 9. Grow leaders who thoroughly understand the work, live philosophy and teach it to others. A good leader is a role model of the company's philosophy and way of doing business. Leader must not only accomplish his or her tasks but also have good people skills. A good leader understands the work and its details and teaches others. (Liker 2004)

Principle 10. Develop exceptional people and teams who follow your company's philosophy. A strong company culture consists of shared values and beliefs that have been lived out for many years. Cross-functional teams that work according the shared philosophy improve quality, productivity, and flow. Teamwork is the key for achieving common goals. (Liker 2004)

Principle 11. Respect your extended network of partners and suppliers by challenging them and helping them improve. Partners and suppliers should be treated as an extension of the business. Challenging business partners to grow and develop shows respect. (Liker 2004)

Principle 12. Go and see for yourself to thoroughly understand the situation. This principle is also called *Genchi Genbutsu* which means "Go and see". Managers and even top executives should spend time on the shop floor to better understand the situation. Going to the source and personally verified observations also increase managers' credibility. (Liker 2004)

Principle 13. Make decisions slowly by consensus, thoroughly considering all options; implement decisions rapidly. Even though consensus process is time-consuming and expensive, it broadens the search for solutions and makes quick implementation possible. Consensus decisions also have strong support behind them. Picking up only one direction without considering alternative approaches might work in a short-term, but in a long run it is not a sustainable way of making decisions. (Liker 2004)

Principle 14. Become a learning organization through relentless reflection *(hansei)* and continuous improvement *(kaizen)*. When a process has reached a stability, the continuous improvements begin. That means removing inefficiencies, minimizing the need for inventory, protecting organizational knowledge by developing motivational succession systems, and standardizing the best practices. Once waste is exposed, the employees should be able to eliminate it by using continuous improvement process (kaizen). The wheel should not be invented again in every project or with each new manager. By using reflection (hansei), managers can develop countermeasures so the same mistakes can be avoided next time. (Liker 2004)

2.2 Takt as a lean method

The term **'takt'** originates from the Latin word 'tactus' which means "touch, sense of touch or feeling". (Haghsheno et al. 2016) Takt can be seen everywhere, for instance, in music or in humans (pulse of a heart). In manufacturing, takt was first introduced in the aircraft industry in Germany, where it was used to prevent overproduction by synchronized production processes. (Abdelhadi 2016) In the lean context, the word takt means a concept interlinked with many other lean tools, methods and concepts, such as standardization and predictability. (Binninger et al. 2017a) According to Taiichi Ohno, the creator of the Toyota Production System, takt is an indicator which reveals when the next production phase is required. (Ohno 1988) For example, if the defined takt is 10 minutes and the production system consists of six production phases of which four take 10 minutes and two take 14 minutes, the system is unbalanced, and thus, the production flow is not smooth.

By Frandson's et al. (2013) definition, the word takt refers to the regular rhythm in which something gets done. In other words, takt is an impulse generator of time intervals with exactly same durations. (Haghsheno et al. 2016) When the rhythm is set and synchronized, the assembly line moves with others in a continuous flow process. Work zones are often kept as small as possible to minimize unnecessary movements of workers. (Hopp & Spearman 2008) However, one must bear in mind that the sizing of work zones and work crews must be done within the limits of both speed of the production line and the capability of each workstation.

Takt has also been used in labor-paced flow lines, e.g. fabrication shops. Ballard et al. (2003) show that a precast concrete fabrication plant can double its productivity if the work is organized in production cells and the process planning and control is based on takt. Fabrication shops are somewhat similar to construction projects since in both, the pace and sequence of work are mostly based on labor instead of machines. (Linnik et al. 2013) However, there is one major difference between construction projects and fabrications shops, because in construction projects, the product is fixed in position and the parts being assembled tend to be big and heavy, and thus, it consumes relatively much time and effort to move the parts through workstations.

The takt concepts created for manufacturing emphasize continuous work flow which is not suffering from any stoppings or waiting of workers. Continuous work flow means that the work in progress is always proceeding, and thus, there will not be any overproduction or inventory in queue. (Linnik et al. 2013) This way of thinking is supported by Toyota's statement that overproduction is the worst of all forms of waste because it almost always generates new, additional waste. For example, if a workstation finishes its work before the following workstation is ready to receive the product, waste of excess inventory emerges between these two workstations.

"The timespan between two beats of a takt is termed as **takt time**." (Haghsheno et al. 2016) Frandson et al. (2013) defined takt time as "the unit of time within which a product must be produced (supply rate) in order to match the rate at which that product is needed (demand rate)." According to this definition, takt time is a design parameter that can be used in any kind of production setting. (Tommelein 2017) At simplest the takt time can be calculated based on the customer demand and the available working time. According to Linnik et al. (2013) takt time is easiest understood with a help of an example of a machine-paced flow line, where every workstation has to complete the required work during the time window when the product is physically at the workstation. If this demand is not met, the incomplete product moves down the line without being ready for the next workstations operations.

Takt planning has its origins in lean production since it strives to set the production rates to match the demand rate. (Heinonen & Seppänen 2016) Takt-based production planning has remarkable role especially in industrial production and manufacturing because takt time can serve as the basis for the predefined and commonly agreed working speed of different fields or workers. Furthermore, takt plays a major role in the just-in-time pillar of the Toyota Production System (figure 2) and most other production systems in automotive industry. (Haghsheno et al. 2016) Equalizing the durations of different working steps by implementing takt planning is an important factor to achieve an ideal one-piece flow.

Takt planning can be either used for individual parts of a process or in the whole value stream to adjust production quantities to meet differing variations in the product demand. (Abdelhadi 2016) The expected benefits of the implementation of takt planning are reductions in project durations and costs (figure 5).

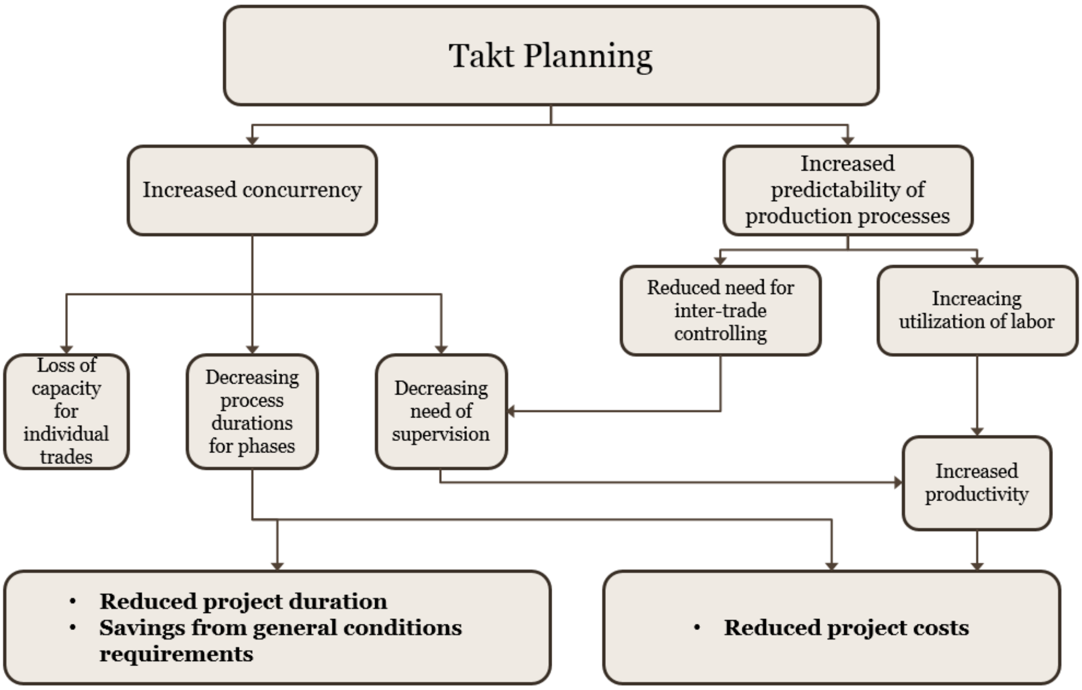

Figure 5. Expected benefits and costs when utilizing takt-based planning and scheduling. (Linnik et al. 2013)

The utilization of takt planning enables one to level work flow and optimize production lines. (Frandson et al. 2014) The goal of the takt planning is to increase productivity by reducing waste, such as waiting, unnecessary movements, and transportation. (Vatne et al. 2016) This can be achieved by optimized team sizes and work packages that fit into the desired production rate. Takt planning reduces non-value-adding time spent by workers and crews, and thus, reduces the overall production costs. When takt planning is used, it is important to ensure that the products do not cumulate between workstations and the workstations do not have to wait for work. (Seppänen 2014) That requires constant harmony in the balance of the production rates of different workstations.

3. LEAN PRINCIPLES AND TAKT PLANNING IN CONSTRUCTION

Construction industry has been under pressure to improve production management practices in the recent years. This is due to factors such as tightened demands, new regulations, bad image, and relatively low productivity compared to many other industries. (Mariz et al. 2012) One way to affect this situation is to implement lean thinking and lean methods to improve the overall construction quality and reduce construction time and costs. According to Frandson and Tommelein (2014), recent experiments have shown that for example takt planning can yield remarkable benefits in terms of time savings, money savings, and improved quality. However, implementing lean techniques in construction is not as unambiguous as it is in manufacturing.

Construction projects are in fixed position compared to manufacturing. In stationary industry, the products and objects flow from one workstation to another while the labor remain where placed (at workstations). In construction industry, on the contrary, the labor force flows from one workstation to another and the construction project itself or its phases can be understood as the objects. In other words, the construction work must be done at a specific time in a specific place, hence, the workstations move through the project rather than vice-versa. This means that in construction processes time and space are linked and co-dependent. (Dlouhy et al. 2016)

The first step in applying lean principles to construction projects is the creation of continuous flow. (Yassine et al. 2014) There are two fundamental types of flows in construction processes. First type of flow processes are material processes which are composed of “the flows of material to the site, including processing and assembling on site”. The second type is “work processes of construction teams which are associated with the material processes.” (Fiallo & Howell, 2012)

Last Planner System

One widely adapted lean method in construction is called Last Planner System (LPS). LPS is a production management system that aims to “improve workflow reliability by shielding near-term work from the variability and the uncertainty surrounding downstream processes” (Emdanat et al. 2016; Ballard and Howell, 1994). LPS is commonly considered as a pull system. It was developed in early 1990s by the Lean Construction Institute (LCI). The purpose of the LPS is to create predictable work flow and constant learning process in programming, projecting, construction, documentation, and the handover of construction projects. (Kalsaas et al. 2015) One fundamental element of the LPS is so-called make ready process, which ensures the identification of all constraints that have any possibility to affect to the planned activities. These constraints will be planned and resolved before the start dates of the activities. This procedure creates a continuous flow of unconstrained work that can be performed with less uncertainty.

LPS emphasizes the identification process of what should be done in order to achieve the predefined goals and keep on schedule. (Kalsaas et al. 2015) This is done via developing a Master Schedule for the project and using backwards scheduling to create a functional pull plan. (Ballard & Howell 2003) The Master Schedule is an executive plan made of major project milestones. The work is planned in accordance with these milestones by creating a lookahead schedule for the upcoming weeks. Identified constraints are removed so the work that **should** be done, turns into work that **can** be done. When the pre-conditions are as ideal as possible, it is time for the last planning objective, which is to commit to work that **will** be done. So-called commitment meetings are usually held in the beginning of each week. The purpose of these meeting is to develop a detailed work plan for the upcoming week. The individual who commits to perform the actual work is the Last Planner. (Kalsaas et al. 2015)

Takt planning

Takt planning converts Last Planner System's Master Schedule into a highly-detailed production schedule, as shown in figure 6. (Frandson & Tommelein 2014) This leads to the basis of takt planning which is to make all buffers transparent and plan each task without major buffers. (Seppänen 2014) Similarly to the Last Planner System, takt planning engages different project participants to an open co-operation at an early stage of a project. However, compared to the Last Planner System, takt planning goes much deeper when it comes to the detailed level of how work can, should, and will be performed. (Frandson & Tommelein 2014) Thus, takt plans can be characterized as highly structured, while plans developed by means of the Last Planner System, tend to focus more on a high level of agility. (Dlouhy & Binninger 2018, private discussions)

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14	Week 15
Area 1	Framing	Plumbing	Electrical	Close up	Drywall	Firetape	Electrical	Tape & Mud	Paint						
Area 2		Framing	Plumbing	Electrical	Close up	Drywall	Firetape	Electrical	Tape & Mud	Paint					
Area 3			Framing	Plumbing	Electrical	Close up	Drywall	Firetape	Electrical	Tape & Mud	Paint				
Area 4				Framing	Plumbing	Electrical	Close up	Drywall	Firetape	Electrical	Tape & Mud	Paint			
Area 5					Framing	Plumbing	Electrical	Close up	Drywall	Firetape	Electrical	Tape & Mud	Paint		
Area 6						Framing	Plumbing	Electrical	Close up	Drywall	Firetape	Electrical	Tape & Mud	Paint	

Figure 6. *An example of a takt plan.*

Takt has been used in several construction projects around the world, for instance, in bridge, building, and tunnel construction. (Haghsheno et al. 2016) According to traditional approaches, takt is highly usable if the product or project has a high level of repetitive tasks and it can be divided into smaller and nearly identical procedures. According to Haghsheno et al. (2016) this is also the reason why it has been uncommon to use takt in building construction where room layouts and levels tend to vary. However, pacing activities to specific rates in building construction is relatively old innovation. (Frandson & Tommelein 2014) One famous example is the Empire State Building, where the pace-makers for the whole construction of 102 floors composed of four takted activities. These activities were steel erection, concrete flooring, exterior metal trim, and exterior lime stone. (Willis & Friedman 1998) The number of takted projects in the building construction has increased since then and recent results indicate that takt planning can lead to significantly shorter lead times and schedules also in the building construction. (Seppänen 2014)

Construction-related takt applications focus on planning work locations that have similar quantities, plans, and task durations. In construction, takt time is the maximum number of days allowed to complete the required work in each location. (Frandson et al. 2013) Similarly to manufacturing, the key characteristic of takt planning in construction is that each trade must complete the required work in each assigned spatial area within a predefined takt time. (Frandson et al. 2015) Once the takt time is set, it is constant throughout the whole phase. Takt can also be used in non-repetitive work because even hardly visible repetitions may become recognizable if the structure of the work process is considered precisely and tasks are divided and detailed in a consistent manner. (Haghsheno et al. 2016)

In general, takt planning is a work structuring method where a construction project is cut into smaller pieces so the overall project would be more manageable. (Tommelein 2017) The implementation of takt planning and takt control prevents overproduction, reduces inventory and lead times, and stabilizes process durations. (Haghsheno et al. 2016) It also reduces the variability of construction processes by standardizing the activities across right-sized geographic areas within distinct work phases. (Linnik et al. 2013) The goal is to have a steady stream of predictable and properly sequenced work across the defined geographic areas by using appropriately planned working crews. The production capacity becomes higher through the optimization of the continuous flow.

If the production moves faster than the takt, the job buffers begin to emerge. (Kenley & Seppänen 2009) On the other hand, if the production moves slower, tasks will take longer and delayed preceding tasks will immediately cause further delays to the following tasks. (Yassine et al. 2012) In other words, takt is an optimal progress rate of all construction activities included in the takt plan, thus the tasks with different workload must be forced to have same durations. This can be achieved, for instance, by fixing the crew sizes, working methods or machine capacity. (Seppänen 2014)

In manufacturing takt is defined by customer demand, e.g. how many cars must be produced in one day. Therefore, the takt in manufacturing is relatively easy to calculate. In construction, defining the most optimal takt is not as easy because defining the demand rate is more complex. One solution is to define the time available to finish the work and verify it in order to base the demand on it. Another solution is to find the slowest trade or activity, also called as bottleneck, and check the feasibility of improving its capacity. (Frandson et al. 2013) Similarly to the look-ahead planning used in the Last Planner System, the deliverable milestones can be used as the starting point for the reverse phase scheduling. If the activities are distributed appropriately and the production rate of each activity is fixed within feasible limits, it is possible to meet the set takt time. (Yassine et al. 2014)

Frandson et al. (2013) emphasize the importance of multiple iterations to define the correct takt time. It is crucial to first understand the sequence of different work phases before creating a proper takt plan. (Frandson & Tommelein 2014) Developing a reverse planning schedule and sharing information can help the project team to better understand the sequence of the trades. Sharing information within the team prevents confusion even if the information is incomplete. However, the iterative nature of takt planning creates challenges in reverse planning schedules because if schedules are designed by means of specific takt time and takt areas, they become somewhat fixed and therefore it requires additional work to change them if the takt time or takt area structure must be rebalanced for one reason or another.

Frandson et al. (2013) identified six phases that must be iterated collaboratively until a viable takt plan emerges. The six-phase process identified by Frandson et al. (2013) consist of the following phases:

1. Gather information and understand the individual trade activity requirements.
2. Define areas of work (takt areas) in order that each takt area includes all locations that have same production rate for a certain task.
3. Understand the trade activity sequence and order by trade.
4. Understand the individual trade durations and apply the durations (bottleneck tasks).
5. Balance the workflow.
6. Establish and manage the production plan.

The production systems in construction differ from the production systems in manufacturing also in terms of organizational features. Production systems in construction are project-based and contain various number of contracts between different parties involved. Project organizations are temporary and that’s why it is important to design the production system actively and in collaborative atmosphere where all those who are specifically involved to perform the work, can ask questions about how other parties would like to perform their work, what resources they need, what kind of crew sizes they favor and in which sequence the work should be carried out. When all this information is known for a specific work sequence, the project team and trades can commit to a production schedule. The production schedule includes all personal constraints of different trades and maintains an amenable work flow. (Frandson & Tommelein)

Usually the major project milestones arise from the client's needs and requirements. The input of the client gets included into the takt plan right after the team has a common vision for execution and the trade sequence. This acts as a starting shot for the project-pulled takt planning. (Haghsheno et al. 2016)

Takt planning stems from dividing construction project into small time segments and spatial areas that have clearly determined and structured work packages. (Haghsheno et al. 2017) The durations of different work packages for each trade are calculated and a consistent production speed can be achieved if all trades agree that the work packages require substantially same amount of takt effort, e.g. one week or one day. This means that after each takt, all trades should have completed all required work in their own takt area. Achieving a consistent production speed is important because it leads to a stable construction process and reduces constraints.

According to Haghsheno et al. (2016) deriving a common production speed for different trades is the most challenging part of takt planning. Takt planning provides a good baseline and clear lookahead into the future by means of work that must be performed by each trade.

Takt planning also enables the creation of project-specific quality assignments. These quality assignments meet five criteria that are definition, size, sequence, soundness, and learning. (Frandson & Tommelein 2014) A collaboratively created takt plan starts to indicate the definition, size and sequence for assignments to be committed to. This allows last planners to focus on identifying the soundness of the assignments, e.g. by ensuring that all prerequisite work is done, the materials are on hand, and the design is complete. Learning comes from the clarity whether the work is progressing as planned or not.

4. TAKT INTEGRATION IN USE IN GERMANY – THE KIT APPROACH

Takt principles have been used in German construction industry since the 1970s. (Binninger et al. 2017a) However, the focus of these approaches was only for the purposes of planning. In 2007, Professor Fritz Gehbauer started a lean movement in Germany with a special focus on contractual models and collaborative approaches, such as the Last Planner System. Several other lean methods and approaches were also developed during the following years. One of these was based on a takted system for operational execution. This method included many characteristics of a modern German takt approach which, from now on, is called Takt Planning and Takt Control.

Unlike the takt approaches created in the 1970s, Takt Planning and Takt Control focuses on both planning and controlling. (Binninger et al. 2017a) It has been tested and used successfully in several construction projects. This approach is based on a process chains that are composed of several parts or sub-processes with equal duration and short cycle control of the processes. In the past 10 years, certain German companies have mastered this approach and it has also been further developed at Karlsruhe Institute of Technology (KIT). (Dlouhy et al. 2016) It was first developed for construction projects that have a clear repetitive nature, e.g. hotel construction. The approach was later applied to other building types, such as residential and office buildings. (Binninger et al. 2017a)

The core idea of Takt Planning and Takt Control is to ‘force’ the process into a uniform flow by adjusting the system to the uniform takt. (Binninger et al. 2017a) A short takt means high level of uniformity and control over the system, and vice versa.

While takt in manufacturing is usually set to minutes or even seconds, Kaiser (2013) recommends to use weekly takt in construction. The reason for this is the instability of construction processes and the difficulty to implement takt less than two days in practice. However, there are several successful examples of shorter takt in construction, such as 2,5 day takt, 2 day takt, daily takt, or even hourly takt. (Heinonen & Seppänen 2016) This means that takt time should not be considered as a fixed number that fits for every project, but rather as a number that should be defined for each individual project to serve best its nature and purposes.

4.1 From the product perspective to the process perspective

A general opinion in the construction industry is that construction projects are seldom repeated and highly unique. (Haghsheno et al. 2016) From the product perspective, it is easy to agree with that statement. However, from the process perspective, similarities can be recognized in greater detail.

A simple example that demonstrates the difference between the product perspective and the process perspective is painting. From the product perspective, the color of the wall can vary in numerous ways. It can be blue, red or white. The paint itself might be matt-finished or glossy. The product perspective emphasizes observable features of finished products. On the contrary, the process perspective does not 'care' about the color of the wall or type of the paint used. The process perspective emphasizes actions and sub-processes that must be done in order to finish the product. According to the process perspective, it does not matter whether the wall is blue or white. What matters is the process and its sub-processes.

The painting example is simple and one may say that it cannot be generalized. Let's take another example which is more complex. Let's consider a building that has many functional clusters that all require different types of artificial lighting. Some lamps are flushed while some are hung from the ceiling. Some rooms require more luminosity and therefore the lamps must have high luminous efficiency. Lamps in the lobby are big and flamboyant while lamps in office rooms are small and inconspicuous. Some rooms might require adjustable lighting. From the product perspective, there is a countless number of different products and it is very difficult to recognize similarities and repetitions. However, from the process perspective the similarities can identified, because regardless of the type of a lamp, the installation process contains many repetitive steps. To install a ceiling light, the electrician must almost always use a man lift or ladder to reach the ceiling. He must also do the wiring and grounding, connect the wires to the electrical grid, do all necessary functional checks, switch the lighting system on, etc. From the process perspective, again, it does not matter how the observable finished products look like and what are their features. What matters is the process.

Through these identifiable repetitions, standardized processes at the construction site become feasible and beneficial. The aim of takt planning is to recognize these processes, implement a project-pulled schedule, and plan to optimize the performance of these processes. Traditionally, construction projects are completed on an individual basis. This has led to a situation where the potential of highly standardized process structures has remained hidden and different phases in a construction project are mostly optimized individually. (Dlouhy et al. 2016) Ehrlenspiel (1999) calls this phenomenon as 'over the wall' approach because when the optimization is made only for one individual construction phase, the information is given to the next phase over 'invisible walls'. Lot of information vanishes during this process, and thus, a transparent value-creation process binding to all project participants, does not exist. (Dlouhy et al. 2016)

By takting a product, one can master only certain products. By takting a process, one can master any kind of products. (Dlouhy & Binninger 2018, private discussions)

4.2 The three-level method

Dlouhy et al. (2016) developed an approach, called the three-level method, to make the construction processes more transparent to all parties, and thus, avoid the information losses described above. The three-level method is based on a three-level hierarchy model where "every level is structured to be built upon the previous level in terms of spatial and time factors". (Dlouhy et al. 2016)

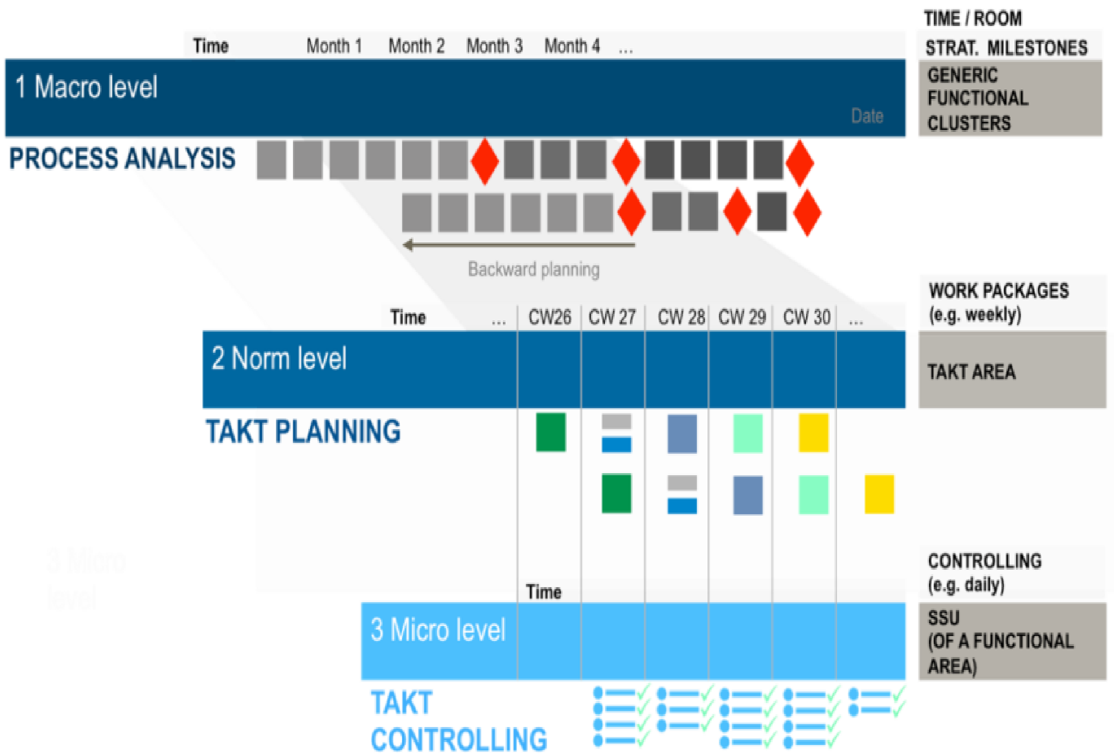

Figure 7. *An overview of the three-level method. (Dlouhy et al. 2016)*

The three levels and their hierarchy are illustrated in figure 7. All three levels and their features are explained in a more detailed way in the following three chapters.

4.2.1 Macro Level – Process Analysis

The steps of the process analysis are comparable to the steps 1-3 of the six-phase process identified by Frandson et al. (2013). The goal of the process analysis is to divide the project into different work areas and define an ideal trade sequence. (Haghsheno et al. 2016) All this is done from the perspective of creating value to the client. (Dlouhy et al. 2016) The objective is to discover the potential clashes and define dependencies. When the project team has agreed on a common vision for completing the project, the client steps in. The client determines the most important milestones, also known as the project milestones, based on the prioritization of the functional areas. In collaboration with the client and by utilizing the existing data from previously executed projects, the project team can now start the project-pulled takt planning. Step by step, and through eliminating time and product constraints, a generic project structure begins to emerge. (Dlouhy et al. 2016)

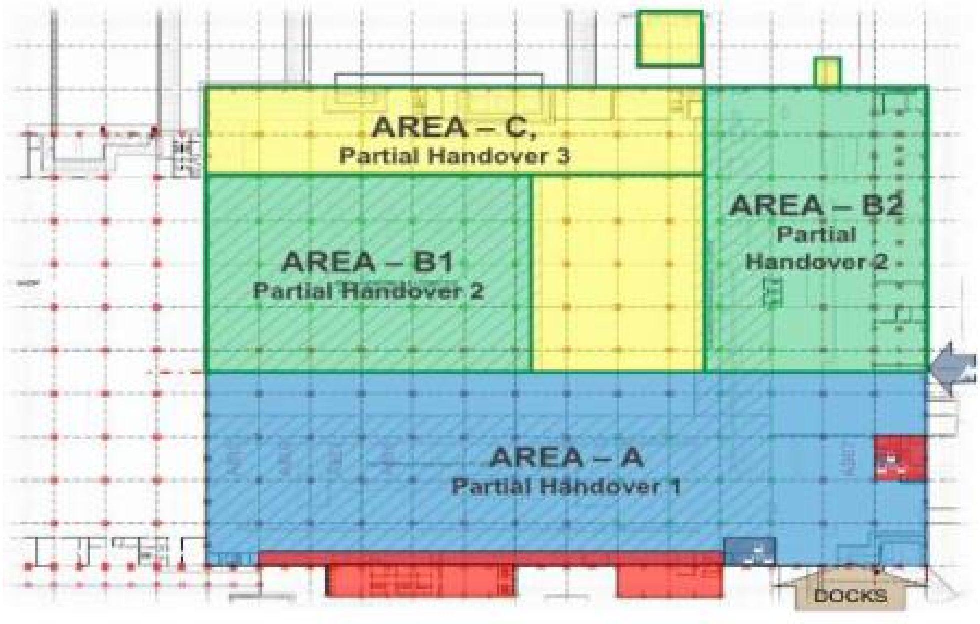

Figure 8. *Functional areas and client's spatial area prioritization. (Dlouhy et al. 2016)*

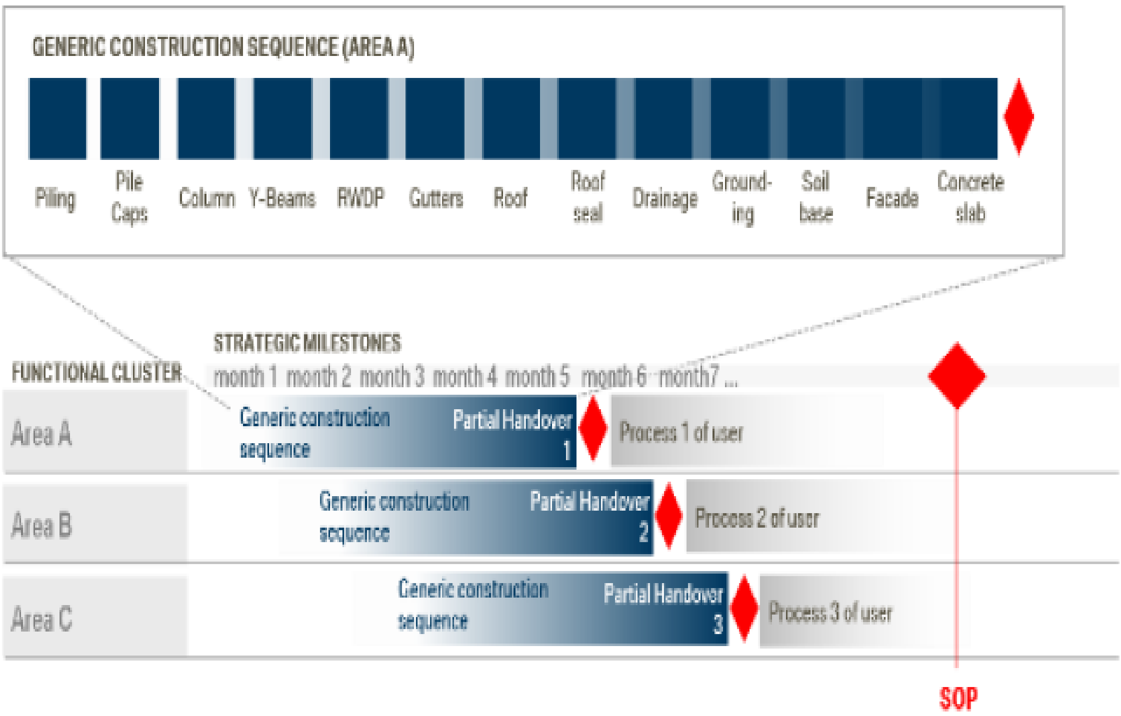

Figure 9. *A generic milestone plan at the macro level. SOP stands for Start of Production. (Dlouhy et al. 2016)*

Figure 8 is a visual illustration of the categorization of the client's spatial area prioritization. Based on this, a generic milestone plan can be created. Figure 9 represents a generic macro level plan that shows the client-defined milestones, their prioritizations, and the generic sequence of works.

4.2.2 Norm Level – Takt Planning

A workable takt plan is developed at the norm level. (Dlouhy et al. 2016) This is done by reflecting the client's requirements, e.g. spatial prioritization, building time, and spatial divisions according the structure defined at the macro level. The takt planning method developed at the Karlsruhe Institute of Technology contains 12 steps and it is based on the three-level method. (Binninger et al. 2017a) By following these steps collaboratively, the project team can create a systematic takt schedule (takt plan). The 12 steps are shown in figure 10.

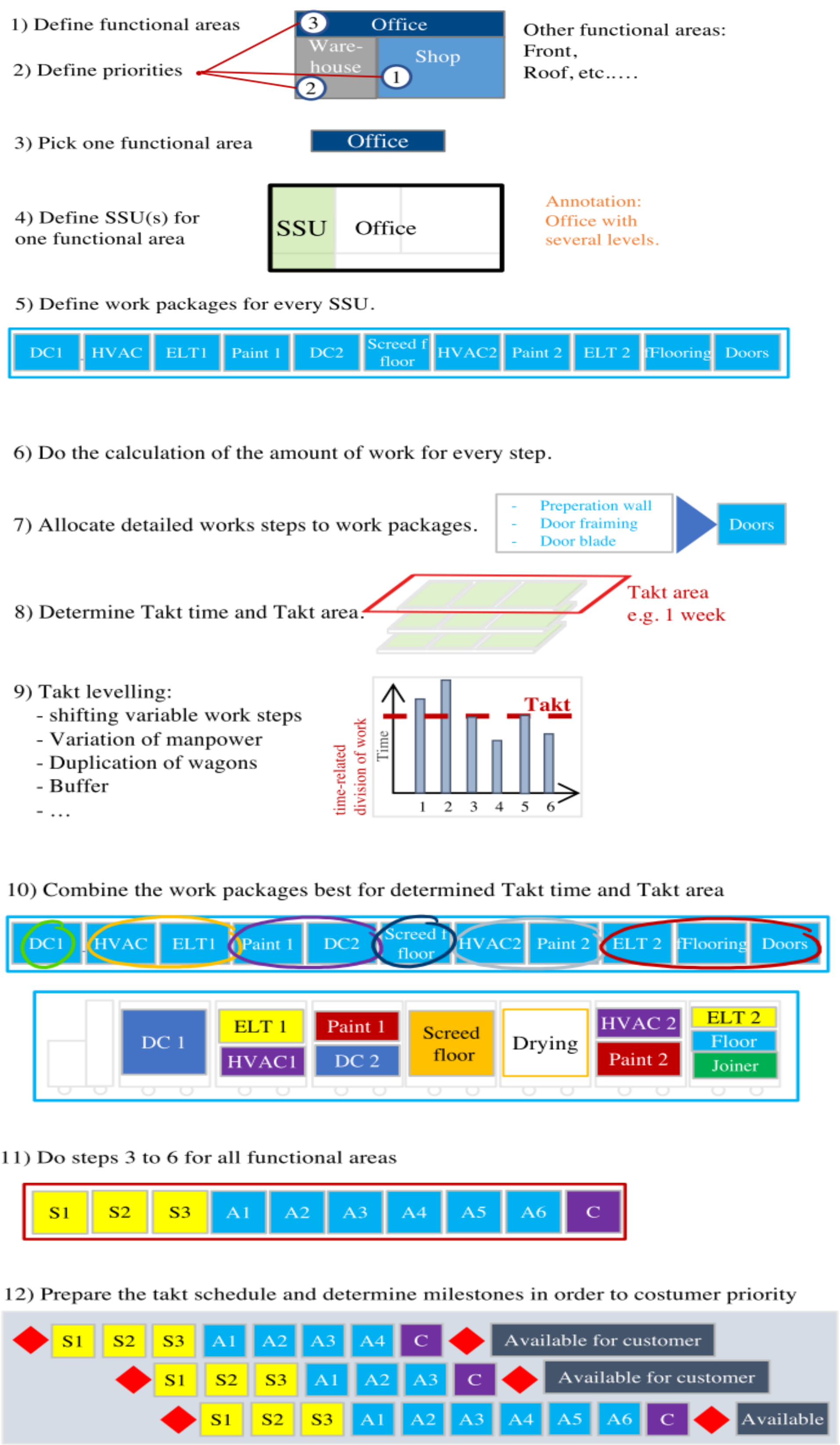

Figure 10. *The 12 steps of Takt Planning. (Binninger et al. 2017a)*

Takt planning starts with dividing the project into functional areas. These are the areas that will be carried out by various process sequences during the construction work. The functional areas will then be prioritized and sorted according the client's wishes (macro level). After the prioritization, one selected area will be divided into SSUs. SSU stands for a Standard Space Unit which means the smallest repetitive part in an area. SSU is the smallest replicable spatial area and it has two essential features. First, SSUs cannot be further divided within defined work sequence. Second, all SSUs can be finished independently of one another. Figure 11 illustrates the hierarchical structure of a project's division into different spatial areas.

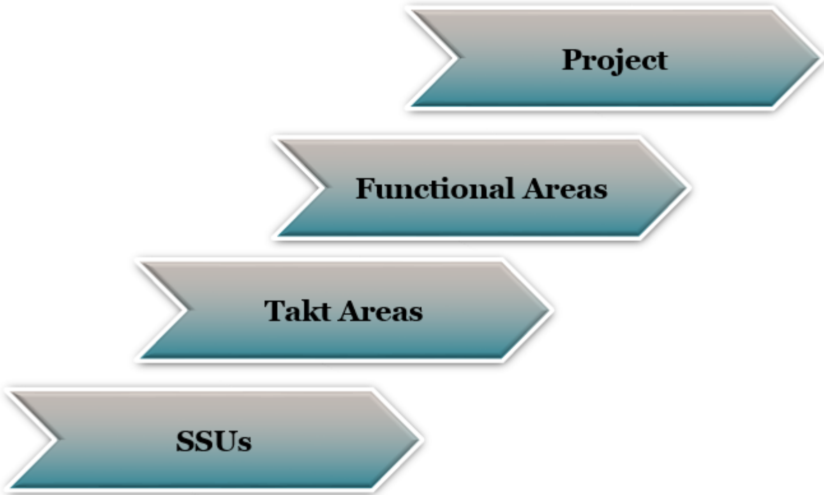

Figure 11. *The hierarchy of different spatial areas of a project.*

By dividing the project's spatial areas into SSUs, it is possible to harmonize performance factors, and thus, find an optimal way to execute the work. In step 5, the project team collaboratively defines the work packages for each SSU. This can be done by using either actual or reverse order planning.

Step 6 is for determining the quantities for the SSUs and multiplying them by performance factors. According to Binninger et al. (2017a) this is the most important piece of the method. After that, the working steps are bunched up into work packages based on the traditional division of works. SSUs are then organized into more practical combinations, called takt areas. Takt areas are also defined according the client's spatial prioritization (macro level). However, it should be noted that there are always limitations and dependencies in all kind of adjustments. This means, for example, that some work steps might require certain minimum amount of manpower, or the minimum size of a takt area is dependent on the team size. (Haghsheno et al. 2016) Figure 12 illustrates how a project has first been divided into SSUs and how SSUs have then been combined into takt areas.

Figure 12. *An example of the division of a functional area into takt areas and SSUs. (Dlouhy et al. 2016)*

One takt area is allocated to one takt time, which is often predetermined according the wishes and demands of the client. The takt time can be calculated by using the following formula:

[1] $$Takt\ time = \frac{Content\ Takt\ area\ (m^2) * Effort\ Value\ (\frac{h}{m^2})}{Selected\ Manpower}.$$ (Haghsheno et al. 2016)

Based on the current experience, a good amount of work per one takt is approximately 85-90 % of the calculatory average. (Dlouhy & Binninger 2018, private discussions) This figure depends on the stability of the processes. It means that for example in one week takt, on average, all work should be finished approximately in the Friday midday. The purpose of these 10-15 % buffers in every takt is to manage the variability and changeableness of the construction processes. By including these small buffers to every takt, it is possible to have more realistic promises, more controllable processes, and better balance between different working phases. Higher calculatory amount of work would increase the amount of delays and unfinished takts. According to Dlouhy and Binninger (2018), it is better to have a stable and continuous process flow where the work performance is approximately 10-15 % below the calculatory average, than 100 % optimized process which is vulnerable to various disturbances.

But how exactly is the size of and workload per one takt area defined? Usually, at the first place, work packages are unsuitable in terms of the planned takt time. If the calculated takt time does not match with the wishes and demands of the client, it must be adjusted.

Adjustments can be done by reducing buffer times or by further optimizations. (Haghsheno et al. 2016) Figure 13 shows some harmonization operations that can be used to level the work packages. One option is to manipulate the time required to perform the work by using bigger or smaller working groups (figure 13, 2 Improving). Another option is to combine different work packages to make up a single time slot (figure 13, 3 Level-ing). It is also possible to change, optimize or replace certain work steps by using different products or processes.

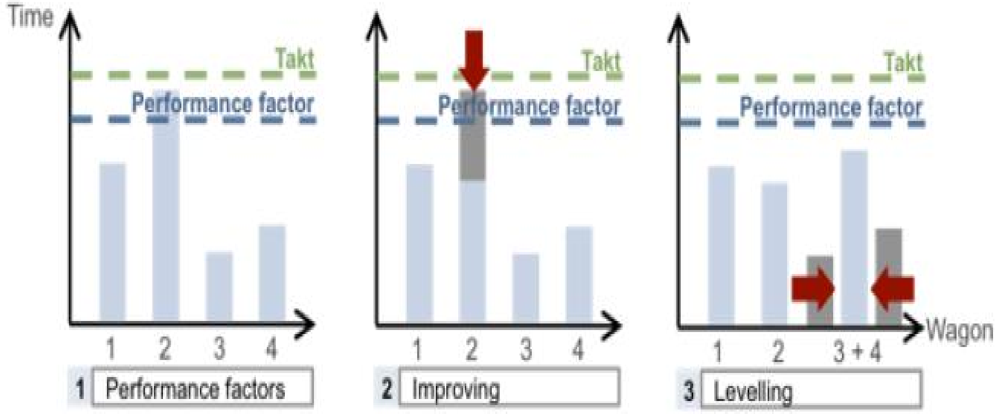

Figure 13. *Examples of harmonization operations for leveling the work pack-ages. (Lean Production Expert 2012)*

Since one SSU cannot be further divided into smaller space units, and it is possible to finish SSUs independently and in any order, SSUs form a foundation for the harmoniza-tion process. Performance factors are arranged into work packages that follow the prede-fined work sequence. (Dlouhy et al. 2016) This sequence can be harmonized by multiple iterations where team sizes and machine capacities are manipulated until the balance is found. It is also possible to manipulate the takt time or the number of SSUs forming one takt area. Harmonization is an iterative process and therefore it is advisable to develop some explanatory tools to visualize the iteration process. One example of that kind of a tool is a harmonization table (figure 14).

Trade Sequence	SSU	Performance factor / SSU	Man-power	Duration / SSU	Takt area	Performance factor (total)	Levelling (Takt time = 5 days)
Piling	5 piece	5*160 min.	4	40 min.	60 pieces (with 2 Takt areas)	5 days	W1
Pile Caps	2 piece	2*480 min.	4	120 min.	13 pieces	3.25 days	W2
Column	1 piece	1200 min.	5	240 min.	7 pieces	3.5 days	W3
Y-Beams	1 piece	800 min.	5	160 min.	5 pieces	1.67 days	W4
RWDP	1 piece	320 min.	2	160 min.	6 pieces	2 days	
Flat gutters	2 piece	2*80 min.	5	16 min.	30 pieces	1 day	
Gutters	3 piece	3*300 min.	5	60 min.	16 pieces	2 days	
Roof	1 grid	3840 min.	8	480 min.	5 grids	5 days	W5
Roof seal	1 grid	1920 min.	4	480 min.	5 grids	5 days	W6
Drainage	18 m	18*149.33 min.	7	21.33 min.	90 m	4 days	
Grounding	18 m	18*10.67 min.	2	5.33 min.	90 m	1 day	
Soil base	324 m^2	324*10.37 min.	7	1.48 min.	1.620 m^2	5 days	W7
Facade	2 piece	2*240 min.	5	48 min.	10 pieces	1 day	
Concrete	360 m^2	360*20 min.	15	1.33 min.	1800 m^2	5 days	W8

Figure 14. *An example of a harmonization table. (Dlouhy et al. 2016)*

According to Haghsheno et al. (2016) "The most challenging part of takt planning is to derive a common production speed for the individual trades." In the harmonization process, the required time for one takt area stems from the planned time cycle and floating buffers. It is crucial that the time required to complete one work package is less than or equal to the duration of one takt (takt time). One important goal of takt planning is to achieve a stable construction process and its sub-processes by defining workloads that are as evenly matched as possible across different trades. (Haghsheno et al. 2016)

Harmonization is completed alongside the leveling of the work. The purpose of the leveling is to balance and stabilize the work load. Work packages are bunched together as so-called wagons, which are further combined as so-called Train of Works or just Train. The sequence of wagons arises from the actual sequence in which the work packages will be performed. Figure 15 illustrates the hierarchical structure of a train.

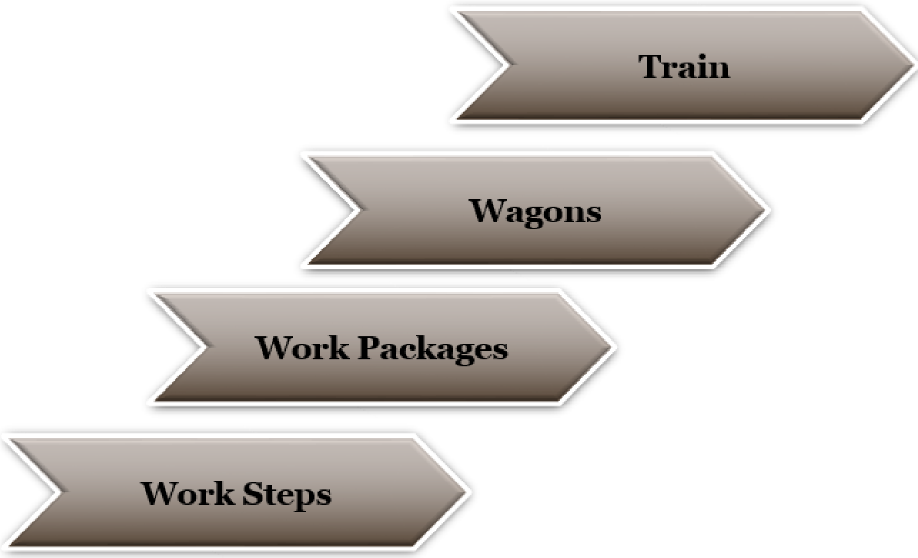

Figure 15. *The functional hierarchy of a train.*

Steps 4-10 are then repeated for other functional areas. The final step is showing the result in a takt plan where the information is transferred into a visual and explanatory form. Figure 16 presents a takt plan that has been created according the spatial prioritization illustrated in figure 8, divided into takt areas as presented in figure 12, and harmonized by using the harmonization table of figure 14.

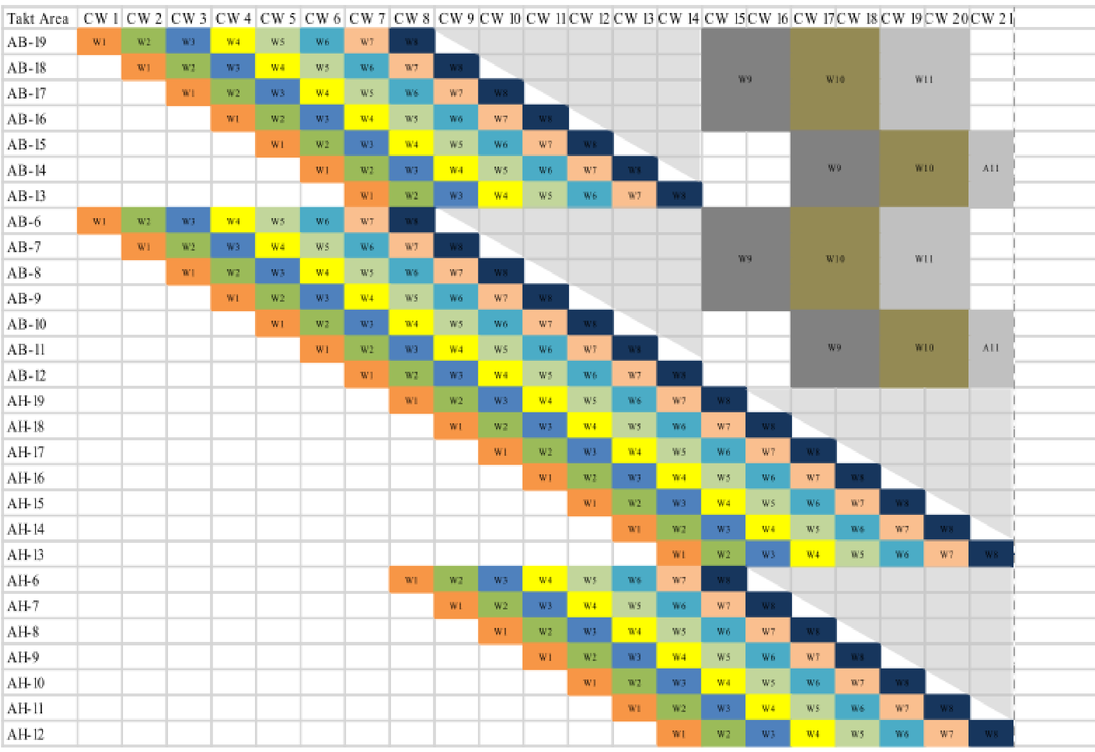

Figure 16. *A takt plan that is developed in accordance with the client's spatial prioritization. (Dlouhy et al. 2016)*

As can be seen in figure 16, sometimes it is reasonable to ‘build’ more than one train to completely cover the value creating and repetitive processes. However, also non-repetitive processes and working areas, which are composed of both time dependent and time independent work packages, must be included as part of the production. (Haghsheno et al. 2016) Hamzeh et al. (2008) define time independent work packages as ‘workable tasks’, that can serve as a buffer tasks if defined work packages cannot be executed in planned sequence or time cycle.

A takt plan consists of three dimensions. (Dlouhy & Binninger 2018, private discussions) These dimensions are

- takt time (x-axis),
- takt areas (y-axis), and
- work contents (the colored ‘squares’).

The spatial entity/time slots are filled with value creating work content. (Haghsheno et al. 2016) The combination of these three dimensions is one takt (specified work content in specified space and time). (Dlouhy & Binninger 2018, private discussions) It is important to separate these three dimensions from each other in order to avoid misunderstandings.

4.2.3 Micro Level – Takt Control

Daily management at the construction site is done at the micro level. It contains weekly and daily takt meetings, short-cycled control, and proactive adjustments to the original takt plan developed at the norm level. Takt meetings are usually held at the construction site or in the site office. The general contractor organizes and leads the daily meetings. Representatives from different trades (sub-contractors) are also participating. The most important agenda during these meetings is to look through the adjustments between the planned working steps and the current project status, and define how the required measures could be implemented to complete every takt in the planned time cycle. (Kenley & Seppänen 2010) From the client’s point of view, and in order to have a well-controlled construction project, it is important to recognize whether or not all tasks and work packages are getting completed at the right time. (Haghsheno et al. 2016) All planned work should be performed according the takt plan at the end on every takt. Short time cycles help to recognize occurring disruptions and enable immediate early-stage reactions.

One must bear in mind that takt plan developed at the norm level is not written in stone. Flexibility must be the core idea of standardized building and design process. (Dlouhy & Binninger 2018, private discussions) This means that also the takt plan is flexible and it should rather be considered as constantly evolving baseline plan for the execution of work.

The flexibility emerges from different short-cycle adjustments that must be performed if something does not happen as planned. According to Dlouhy and Binninger (2018, private discusisons) takt control covers most of the overall TPTC-process. This means that changes happen and adjustments must be performed all the time and in every phase of a construction project. Binninger et al. (2017b) have identified and listed 31 adjustment mechanisms and categorized them into three categories according to their empiric observations and evaluation of how frequently different adjustment mechanisms have been used in real-life construction projects. Table 2. lists some of the adjustment mechanisms belonging to the category A, which represent mechanisms that have been used in over 30 cases.

Table 2. *The most common adjustment mechanisms in takt planning and takt control. (Binninger et al. 2017b)*

Name	Description	Effect
Decoupling of takt areas	Reorganizing the sequence for completing takt areas.	Change in the order in which the areas will be completed.
Empty wagon	Planned buffer times, e.g. drying time.	Visualization of required buffers. The construction time increases.
Phase interlinking	Some process phases require smaller or bigger takt areas than others. Adjustments for these differences result in efficiencies.	Optimization of the construction process
Soft start	In multi-train projects, it is possible to delay following trains in order to learn from the starting train.	More stable construction site processes. However, this also increases the construction time.
Train stoppage	Stopping the whole construction process due to a problem.	Increased construction time.

The amount of required and performed adjustments is also an indicator of stability. (Haghsheno et al. 2016) This indicator is comparable to the PPC-indicator (Percentage Plan Completed) used in the Last Planner System.

5. FLOW IN DESIGN PROCESSES

The main target of continuous flow is to streamline the project as a whole. (Keskiniva et al. 2018) However, design activities are very different by nature when compared to construction production, since unlike construction production, design is not a straightforward process. Designers begin with doing several estimations about loads and other stress factors. After that they prepare several alternative sketches and solutions to solve different design assignments. The designers must always ensure that solutions fulfil all the statutory requirements as well as customer demands for the project. (RT 10-11128 2013)

Design process produces information and potential value; thus, it can be considered as both a production process and a creative process. (Ballard 1998; Koskela et al. 2013) This means that designing also contains two significant perspectives that may fictitiously contradict with one another. The flow perspective is related to waste while customer value perspective is related to losing value.

Varying and unstable production process is usually considered as adverse source of waste. In design process, however, variability may be favorable source for generating potential customer value. For example, the preparation of many alternative solutions can be considered as waste from the designers' perspective, but without alternative solutions, the most valuable solution could remain unobserved.

In order to create an effective flow in design process, the design process itself and its impacts on the construction production and practical issues must be understood. Lindgren (2016) lists seven things that must be identified and acknowledged to make the design process flow:

1. over-design,
2. iterative nature of design process,
3. redesign,
4. poor sharing of information,
5. ineffective workflow,
6. poor design, which causes waste in production, and
7. too expensive design solutions.

According to Keskiniva et al. (2018) the cornerstones in achieving continuous flow in design process are detailed schedule planning and designer-specific resourcing. In manufacturing and construction production, the continuous flow emphasizes movements of physical subjects, i.e. products or working groups. In design, the focus is rather on making the information flow. This requires broad understanding of the project and constant interaction and functioning collaboration between different designers and design disciplines.

Lack of collaboration in design creates waste. For instance, missing information and unrealistic schedules might cause delays and mistakes. Uncertainty management and feasibility of the finished drawings are also critical challenges in continuous information process flow.

At an operational level, the problems in design will typically result in various harmful consequences. According to Soto (2007) amongst many other things, some of the most significant consequences of poor design are:

- Drawings are unfinished and require additional supplements or cause improvisation on construction site.
- Drawings are unclear or too rough.
- Customer demands are not taken into account or it is difficult to discern them. This leads to late readjustments, delays and unexploited design solutions.
- Coordination within and collaboration between different disciplines falls down. This causes conflicts and incompatible drawings.
- The level of defects in design is high, which results in feasibility problems and high additional costs.
- The costs of design are decreased at the expense of quality.

In construction production, the waste of inventory can easily cause longer lead times, higher costs, and delays. (Keskiniva et al. 2018) Varying and unstable production rate is significant factor in waste generation. Varying and unstable production rate is also difficult to be planned and controlled because it contains a lot of uncertainty. For that reason, variability in construction production is typically considered as waste.

Design process differ from production process by its iterative nature. Thus, the variability of early drafts is often beneficial in design. Preliminary concepts contain alternative solutions, and by utilizing different iterative methods, designers can detect possible design errors and develop potential and feasible solutions to avoid them. (Ballard 1998)

According to Soto (2007), the waste in design process consists of two main components. These components are unnecessary redesign and workflow-related non-value-adding activities. According to foreign experiments and reports, even 60 % of project managers' time in high-standard projects might be wasted in customer-related changes, resulting uncertainty management and re-instructing the contractors. (Sacks 2014)

Iteration that can be eliminated without value loss, is also waste. (Ballard 1998) This so-called negative iteration can compose as much as 50 % of designers' working time. Unnecessary iteration may also be caused by poorly organized design. (Keskiniva et al. 2018)

Negative iteration is especially remarkable in renovation projects because renovation projects tend to have higher level of uncertainty and unexpected findings than new construction projects. Existing conditions of the building under renovation are affecting to design in two ways. First, conditions define the budget and cost requirements for the design solutions. Second, conditions cause several limitations to both architectural and technical design solutions (Mitropoulos & Howell 2002)

Unnecessary iteration can be avoided by taking every phase of the design comprehensively into account at an early stage. This approach emphasizes collaborative and effective team work. The number of iteration cycles can be reduced by understanding the information flow between different design activities, and minimizing the need of backwards-moving information within and between each design phase. The elimination of unnecessary iteration cycles caused by redefining customer demands becomes possible if the customer values and demands for the project are defined clearly before actual design activities are initiated. (Koskela 2000)

Design companies can reduce wasteful negative iteration and over-design by doing redesign only if it serves the purposes of the whole project, e.g. designing first drawings for the purposes of procurement, and doing redesign with higher degree of accuracy for the construction production. This procedure can be called as positive iteration since it creates value for other project parties, and thus, for the project itself. Increasing collaboration and teamwork is one solution to eliminate waste in design processes. (Keskiniva et al. 2018)

For example, HVAC drawings are often designed twice with different level of accuracy; first time for the competitive bidding and second time for the actual execution of work. The first drawings are designed without all necessary prerequisites because at that time, architectural design and structural design are also still in progress. For that reason, drawings contain many guesstimates that must be corrected later. From the designers point of view, this kind of redesign is waste. However, redesigning is usually approved if it is best for the overall project. (Keskiniva et al. 2018)

The management of varying production rate and uncertainty is highly dependent on the information flow within the project organization. (Kivistö & Ohlsson 2013) The more uncertainty there is, the more information must be shared. Poorly controlled and managed information flow will most likely result in unnecessary use of resources, which is clearly waste. Thus, the efficiency and transparency of information processing should be improved, for instance, by using collaborative working methods.

One well-tried collaborative working method is called Big Room working, where designers from different disciplines convene to work in a same room where they can share information effectively without using email or any other electronic information-transmission systems. (Keskiniva et al. 2018) Big Room working suits especially well for big and complex projects, and according to Keskiniva et al. (2018), it is an essential ‘tool’ in making the design processes flow. Big Room working has been experienced as helpful in terms of getting the required prerequisites on time, discussing about drafts and finished drawings, and sharing knowledge appropriately with the right disciplines.

Smaller and simpler projects require lower level of comprehensive special know-how, thus it is not always necessary to assemble for a Big Room meeting. A short-term alternative for Big Room working in small and simple projects is called Knot working. (Kerosuo et al. 2013) The purpose of Knot working is to steer designers, tasks and tools into a brief and intensive problem-solving or task execution event that must be conducted in close cooperation. The 'knot becomes untied' when the problem gets solved or task is executed.

Catenating construction project's design and production as separate sequential phases may cause non-ideal solutions, poor feasibility of drawings, high level of unnecessary adjustment work, and absence of continuous improvements. Design errors and poor decisions made at an early stage of the project are especially harmful because they can have a massive impact on the project's costs, schedule, quality, and safety.

One way to tackle problems caused by catenated project phases is to use project systems that seek to align interests, objectives, and practices through a team-based approaches. A common factor for these project systems is overlapping design phase with procurement and construction phase. Overlapping and collaboration enable effective utilization of expertise and knowledge of the project team's participants to improve the information flow and feasibility of the drawings. (Soto 2007) Examples of this kind of collaborative project systems include Integrated Project Delivery and Construction Management Contracting.

Achieving a stable and comprehensive continuous flow for the whole project requires a lot of work and collaboration from all project participants. According to Keskiniva et al. (2018) the flowing design processes are rare, and sometimes flow in design phase appears to contradict some other project phase's flow or the project's flow itself. In these situations, the design processes typically yield. This is due to the fact that delays in design are relatively cheap compared to delays at construction site. Internal productivity of individual design tasks and phases can be improved by planning internal commissions in order to create more reliable schedules and take account of identified prerequisites and dependencies.

Sometimes the scope of design tends to expand after competitive bidding because designers have not planned their work well enough or they 'forget' to follow their worklists. (Keskiniva et al. 2018) This leads to broad processes without clear boundaries, which is against general lean principles. Worklists describe discipline-specific design processes and are developed to be applicable for projects with varying level of size and complexity. If designers are not following worklists and the scope of design begins to expand, monitoring and steering becomes cumbersome. For that reason, it is advisable to cut design processes into smaller pieces. For example, if the degree of readiness in design is 50 % and the process is not cut into smaller pieces, it might be difficult to know whether five out of ten drawings are 100% finished or all ten drawings are half-finished. Unplanned working methods can easily cause over processing and overproduction. (Keskiniva et al. 2018)

Design companies can gain competitive advantage by developing and practicing new design concepts related to specific types of projects. One way to create a functional flow in design process and avoid expanding scope of work to do is to plan and schedule the required work consistently and in a designer-specific manner. This means detailed definitions for the durations, budgets and resources of different working phases. Based on these definitions, project team can collaboratively create designer-specific schedules. In addition, the designers must be told what has been bid and what the owner is expecting. This helps the individual designer to avoid overproduction and better inform if any unexpected problems are arising. (Keskiniva et al. 2018)

Another option is to create clear and transparent process flow charts. A good process flow chart illustrates when, and in which degree of accuracy, the drawings must be finished so the procurement can be done in time and the production flow can continue without halts. Dependencies must also be presented transparently in the process flow charts.

One fundamental challenge, but also a good possibility to gain competitive advantage, is achieving comprehensive picture about the project as a whole in order to create a realistic and project-specific flow chart. According to Keskiniva et al. (2018) there are not many project managers who are competent enough to truly and comprehensively understand and manage projects that well. Lack of highly competent professionals may result in party-specific problems.

Sometimes construction sites do pull-planned prerequisite requirement schedules for drawings. However, often these schedules do not contain enough time for procurement, owner's decision-making, or governmental authority's acceptance. (Keskiniva et al. 2018) In other words, overall understanding tends to be insufficient. This results in situations where time and requirements for design do not meet one another, and the construction site wants finished drawings too early or with too high degree of accuracy. According to Keskiniva et al. (2018) this is due to the fact that design process and its features are not fully understood at construction site, and on the other way around, procurement and production processes are not clear for designers.

The success of a project is highly dependent on the degree of teamwork and collaboration. More complex the project is, the more collaboration it requires. However, in order to achieve a functional flow in small and simple projects, high level of collaborative methods and teamwork is still needed. Keskiniva et al. (2018) claim that in the future, small and simple projects may not necessarily need eminently extensive collaboration as long as competencies of the project team and its members are good enough.

The optimization should be done for the whole project. Different parts and phases of the project may require sub-optimization, but that should always be done by considering what suits best for the whole project. Sub-optimization can sometimes be purposeful if the earning principles of different project parties contradict with one another. These situations might be extremely harmful for the project, thus they should be avoided. One way for that is to share risks and rewards between major project participants. Sharing risks and rewards is especially common in Integrated Project Delivery Systems, where the compensation of service providers is based on how well they perform their tasks for the good of the project. (Keskiniva et al. 2018)

Another significant barrier is poor communication. Poor communication may occur in every project phase, both within and between different parties. Poor communication consists of, but is not limited to, misunderstandings, incorrect or inaccurate information, lack of information, reluctance to share information, and weak commitment to pursue best for the project. Poor communication could also be reduced by using transparent and collaborative working methods. (Koskela & Koskenvesa 2003)

6. EMPIRIC CASE STUDY – LEAN AND TAKT AT THE TARGET COMPANY

Due to the reasons described above, it seems like it is not necessary to find solutions that are optimized to the utmost when applying lean principles or takt planning in structural engineering in order to make it flow. What is more important is a transparent and stable process. In the end, a harmonized design processes that have been conducted collaboratively and transparently, will most probably result in shorter lead times. Lean design process has several similar features as lean construction process, e.g. buffers can easily be seen, process flows smoothly and continuously, work sequence is known, and dependencies are recognized and made transparent.

Based on the author's own observations and findings about lean principles (chapter 2), takt in construction production (chapters 3 and 4), and flow in design (chapter 5), he developed the first proposal of how the target company should move forward from the current situation. This proposal was introduced to target company executives in two workshops and further developed afterwards. The redesigned proposal was then introduced to other target company's executives in another workshop. The objective of this workshop was to summarize the readiness to adapt and implement takt planning in each three lines of business of the target company. Another key objective of this workshop was to test how author's proposal can be integrated in the target company's strategy and goals.

6.1 Distinctive features of the target company

The focal context of construction-related design and consulting services consist of "competing groups of architects, engineers, project managers, and consultants related mainly to buildings and infrastructure". (Huovinen 2018) Construction-related design and consulting companies only sell their personnel's competencies and professional know-how, thus the most important assets for these companies are human resources and intellectual capital.

The target company is a Corporate Group, which is a distinguished construction-related designing and consulting company, currently operating mainly in Finland. The target company consists of a parent company and three subsidiaries with following lines of business:

- structural design and engineering (including acoustic engineering),
- construction management consulting,
- traditional civil engineering, i.e. infrastructural, underground, and environmental engineering.

Altogether, the target company employs approximately 730 professionals of engineering and construction management. It has agencies in Finnish major cities, e.g. Espoo, Helsinki, Kuopio, Oulu, Tampere, and Turku.

The construction field is dynamic and highly sensitive to changes in the level of costs. This means that companies in the construction field, including the target company, are in constant interaction with their environment. Hence, they tend to behave as open systems (Figure 17). Scott and Davis (2007) point out that "open systems are capable of self-maintenance on the basis of throughput of resources from the environment." Furthermore, participants and subgroups tend to form coalitions in which they receive and process information. Many decisions and actions are also made in these subgroups. Under those circumstances, open systems emphasize processes over structure.

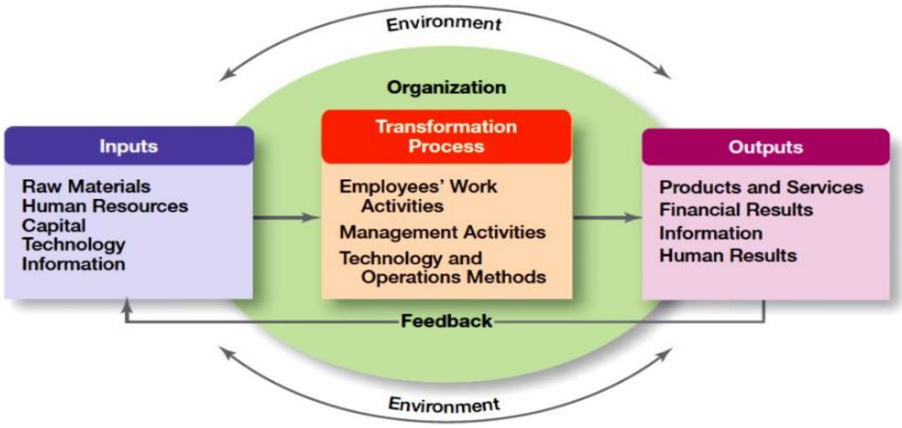

Figure 17. *Organization as an open system and its dynamic interaction with its environment. (Mahesh 2016)*

Target company's inputs are mainly intangible resources such as human resources, professional know-how, and real time information about everything that happens in the Finnish construction field. This emphasizes the role and skill-set of target company's participants, e.g. designers and project managers.

The transformation processes (Figure 17) are made by individual participants or project teams with support of different tools, such as 3D-modeling, "brain storming", and databases of previous projects. The way highly skilled participants use and share their knowledge and professional know-how can be characterized as the target company's most important 'technology'. Other tools and techniques are important too, but they play minor role compared to the brainwork of key employees. The project team's level of function should outnumber the sum of its individuals' performances. This means that the team leaders and project managers play major role in the success of projects.

Target company does not produce any physical products. It only sells its personnel's competence and professional know-how, thus its clients and their needs are always bulked large. At the operational level, the target company's primary goal is ensuring that the project's outcomes match with the clients' wishes, the costs won't exceed the budget, and the project keeps on schedule. Naturally, the target company has also financial goals but those goals can only be achieved if the primary goals are achieved first.

6.2 Takt planning in the target company's typical commissions

In order to get an independent and realistic overall impression about the applicability of takt planning principles in the target company's daily business, the author interviewed and discussed with several structural designers and project managers. All interviews were semi-structured. (Appendix 1) The interview questions were send to 12 designers and project managers, out of which 5 answered.

The answers related to the common problems and challenges were mostly coherent. High level of uncertainty, delayed prerequisites, inefficient working methods, and tight schedules were considered as the issues that require improvements. The delayed prerequisites were considered as highly problematic, because those problems are usually stemming from other project participants. The designers are willing to strive to keep on schedule, but many times the missing information or lacking communication make it impossible.

According to the designers and project managers, the development work is important and it should be supported. New working methods and tools are welcomed, but the implementation should not be done top-down, but rather bottom-up. The communication and coaching should also be done in a consistent manner during the change process.

The development of solutions and proposals for the implementation of takt planning in structural design and other lines of business of the target company requires a clear principle of distribution between two commission types. The first type is structural engineering commissions where the target company is only carrying out tasks related to structural design and engineering. Structural design and engineering, in this context, means any kind of commission that does not include services from the construction management line of business. The second commission type is the commissions that include construction management services. In this type of commissions, structural design and engineering can be bought either from the target company or elsewhere.

6.2.1 Structural design and engineering commissions

Structural design and engineering commissions vary depending on the size of the project and the type the type of the contract. Large and complex projects are normally conducted by several designers while small and simple projects might require only one designer.

The target company's subsidiary of structural design and engineering has 11 business units. Each unit is specialized in certain type of projects, e.g. residential building construction, renovation construction, or industrial facilities. All units operate mainly independently and have reporting obligations to the Corporate Group.

Since there are many independently operating units with different areas of specialization, there are various ways to manage projects in terms of planning, scheduling, resourcing, and controlling the work performance. If the project itself is not takted, there will not be any significant benefits to apply takt planning in structural design. This is mostly due to the fact that the required schedule for structural design stems from the construction production, and the information required for structural design comes from several different sources, for instance, from the owner or other design disciplines. Thus, there will not be much benefits in takting the structural design process if the construction production's need for designed drafts or finished blueprints does not match with the set takt.

From the construction production's point of view, too detailed or too large design packages are overproduction, i.e. the worst waste of all. On the other hand, if the design package is too rough, or it does not consist everything that is needed to perform the work, it does not provide any value to the construction production. The same requirements for design packages are also critical within and between different design disciplines, because if other design disciplines are not following the same takt, the flow of required prerequisite information starts to buffer. This makes it very difficult or even impossible to complete every takt in a planned time cycle. For these reasons, right design packages should be delivered at the right moment, to the right disciplines, and with a certain pre-defined degree of accuracy. This emphasizes the core idea of just-in-time delivery.

More important than takting and optimizing the processes to the utmost in structural design and engineering commissions, is well-planned and managed own work. This includes scheduling and resourcing of the commission, daily management, and required adjustment mechanisms to achieve the goals. Management of own work can be done by means of lean principles. For example, instead of using rough Gant Charts for scheduling and resourcing, project managers can develop detailed Kanban Boards that are more useable in monitoring the degree of readiness of work. Figure 18 illustrates the author's sketch for that kind of a Kanban Board.

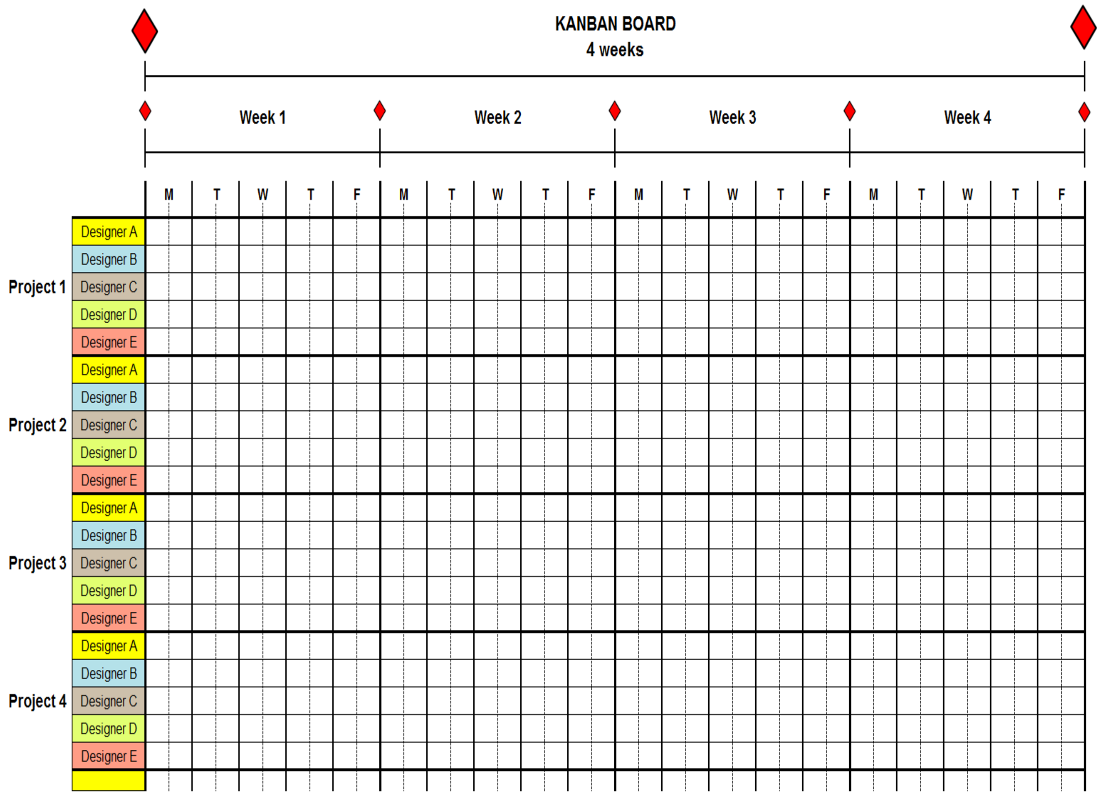

Figure 18. *An example of a Kanban Board for planning, scheduling, resourcing, monitoring, and managing the structural design and engineering commissions.*

The target company's designers and project managers operate in a multi-project environment. Thus, takt planning principles can additionally be included into the Kanban Board presented above. For example, a project manager who oversees the projects 1-4 can plan the schedule and resource usage to follow the takt principles by considering each project as one takt area. In this scenario, different designing entities, such as foundations or facade for the whole building, or only for one block, can be considered as SSUs. Wagons are more detailed design packages, such as strand-cables, expansion joints, or embeds and anchor rods. By color-coding the wagons, the project manager and each designer can easily see what work content each project requires, when it requires it, and who is supposed to do that. By splitting the Kanban Board into small time segments (daily, half-daily or hourly), the project manager can easily monitor how the work is progressing, and carry out adjusting actions if needed.

6.2.2 Construction management commissions

The target company's construction management services consist of ensuring the best outcomes for the customers and their construction projects by providing expertise in construction project management and everything that is related to successful delivery of a construction project. In other words, the target company's construction management services include providing solutions to daily challenges that different parties (owner, contractors, engineers, architects, etc.) face during a construction project.

Usually construction management commissions begin at an early stage of the project. The decisions made at this point will have a huge impact on the project. If the client (owner) decides to utilize lean principles and takt planning in the beginning of the project, it will work as a prerequisite for many decisions, contracts, and working methods to come. This means that construction management commissions enable effective implementation of takt planning.

By implementing takt planning in construction production, it is possible to use backwards scheduling to extend the pull system to concern the previous phases too, and thus, takt the design process as well. In this scenario, the pull planning stems from the construction production's needs, which means that designers can plan and perform their work based on the principles of just-in-time delivery.

If takt planning is integrated into the project planning at an early stage, other design disciplines can also participate in project planning and commit to follow the lean principles and takt plan. If designers work collaboratively to understanding the designing sequence, recognizing dependencies, and making them transparent, it is possible to achieve a continuous information flow where designers do not have to halt their work because some preceding information is missing.

6.3 The best possibilities and ideas to be further considered

In order to get a clear picture of how lean principles and takt could be applied and introduced in the target company's daily business, two workshops were organized. Due to the geographical division of the target company's major branches, workshops were held in different geographical locations. The content was same for both workshops. Workshops were conducted by the author. Other participants were selected to comprehensively represent all three lines of business of the target company. All participants, including the author, were part of the target company's Lean Team. The first workshop was composed of four participants, including the author, whereas the second workshop had five participants.

The objective of the workshops was to introduce the executives to the principles of takt planning, and discuss and discover how, and in which format, takt planning could be applied into usable concepts at the target company. Workshops were designed to be interactive. The author presented briefly the major insights and findings from the literature survey and the empiric observations from the study trip in Germany. Other participants were encouraged to ask questions about and comment on the findings both during and after the presentation.

Based on the brainstorming and observations made during the first two workshops, the author designed first sketches for a plan how lean concepts, e.g. takt planning, could be implemented at the target company. In order to test and further develop this plan, a third workshop was organized. In order to get objective opinions, participants for this test workshop were the author and two target company's executives who did not participate at either of the previous workshops. The third workshop was held in Espoo and it was composed of three participants, including the author.

It is notable, that most of the subjects dealt with, and the ideas developed during these workshops, are business secrets. Thus, only some parts of the workshop contents are reported. The reported content is general and is relevant not only for the target company, but rather for the whole Finnish construction industry.

6.3.1 Workshops 1 and 2 – Applicability of takt planning at the target company

The distribution between structural design and engineering commissions and construction management commissions was considered as a reasonable way to establish the implementation of lean principles and takt planning at the target company. Takting the design processes and making them flow gained broad acceptance idealistically. However, the actual implementation was considered to be challenging and time-consuming. According to workshop participants, at the moment it is more essential to enhance the organizational culture to fully understand the benefits of the lean philosophy, especially the importance of steady and continuous process flow. When the philosophy is adapted, it becomes easier to apply takt into the processes.

One executive said that takt-like planning has been done is some certain projects in a subconsciously manner, meaning that the planning of own work often contains some features of takt planning, although those features have not been particularly identified or named. However, those are just some single features and there is still a long way to develop actual takt plans and takt schedules to be fully utilized and used in projects.

From one design discipline's perspective, many project teams consists of only one or two designers. This leaves only few possibilities for different adjustment mechanisms, such as decoupling of 'takt areas' or soft starts. However, if a designer cannot perform certain tasks for one reason or another, project managers and other designers often check if there is anything to do to solve the issue. This manner of proceeding is highly related to knot working.

There are still designers and project managers who love projects without tight schedules, or projects that have no schedules at all. The absence of schedule might stem from the owner, general contractor, project management consultant, or any project manager. This, however, creates problems, because if the only information about the project schedule is the date of completion, it is impossible to develop good plans for resource usage and time consumption. The number of this kind of projects has been decreasing recently, but full change in organizational and industrial culture is still considered as demanding and time-consuming.

One challenge in making the design process flow is the heterogeneity of designers. An experienced designer might use one week for something that requires three weeks from an unexperienced designer. In order to create a functional train of works within a single design discipline, the harmonization operations for leveling the design packages must be done with bearing in mind that there is a significant unevenness between the skill-set and working efficiency of different designers.

Another challenge is the lack of time for developing and maintaining new and innovative project management methods. This is due to the earnings principle where the profit comes from the actual designing tasks and activities performed for projects. The degree of work to be invoiced should be high, which means that most of the project managers do not have time for, or are reluctant to doing ‘additional’ work for developing better and more efficient working methods.

One project manager might have 10-20 ongoing projects. The scope of these projects can vary from 10 to 10 000 hours of work. Typically the projects are in different phases and the designers working for each project are also varying. For this reason, it is relatively difficult to find a one comprehensive working method that suits for all projects.

Some of the target company’s independently operating business units have organized according to team structures where one project manager is in charge of one team of designers and a certain set of projects. This kind of team structure enables detailed designer-specific scheduling and resource planning. The Kanban board (figure 18) was considered as a good tool for planning, scheduling, resourcing, monitoring, and managing the structural engineering commissions in these team-structured business units.

Many designers have got used to be told what they need to do, when everything must be done, and in which degree of accuracy the work must be performed. For that reason, some designers may not even know what prerequisites they need. In reality, design processes, as well as many other projects’ sub-processes, are like cogwheels that constantly require new input (prerequisite information) in order to avoid unnecessary halts and defects. Lacking professional competence in requiring what needs to be required is considered as a significant problem throughout the whole construction industry.

The target company’s executives are definitely interested in to implement lean principles and takt planning to make design processes flow. At this moment, executives are pursuing to gain knowledge and increase their understanding of different lean concepts in order to be better able to do right decisions and implement the most suitable lean tools and methods. Takt planning is considered as a highly potential method to be implemented in the future.

6.3.2 Workshop 3 – Implementing and testing the ideas

It is impossible to get rid of the heterogeneity of designers. There have been, and there will always be designers who are better and faster than the others. What needs to be done is to train and encourage the slower designers for better performances. In addition, internal project management must be on a level where scheduling and resourcing can be done by taking the heterogeneity of designers into account.

The author's empiric observation about traditional design process where designers only know the start date and the date of completion, was considered significant, because this manner of proceeding does not enable good steering. A traditional Gant Chart seems to be too rough and unsuitable way for presenting schedules and resourcing plans in design processes. A long Gant-like bar in a schedule or resourcing plan tells of unsuccessful planning of own commission.

Poor schedules and prerequisite demands may result from various sources, such as project parties or project's complex nature. A relevant question is "who is the one that raises the red flag?". If some external person gives a schedule to a designer and tells to design according to it, the designer must be competent enough to 'blow the whistle' and open a transparent discussion about what is reasonable, what is not, and is the schedule even feasible at all. There are several things, such as task allocations and designing milestones, that must be agreed on collaboratively and transparently. These discussions are rare nowadays and their absence is a serious barrier to successful projects.

The scheduling should be based on the milestone-thinking. Milestone-based schedules enable designers to focus on smaller and more controllable entities. Rather than considering when everything must be done and finished, a designer can focus only on these smaller entities at a time.

Project systems where risks and rewards are shared between major project participants should be supported. Many other project systems do not encourage to collaboration. On the contrary, traditional project systems might lure certain project parties to take advantage of blaming other parties for delays in order to get some compensation in money. For that reason, Integrated Project Delivery and other collaborative project systems should be used in order to get the most of takt planning in both construction production and design.

When takt planning in structural design is tested and piloted in first actual projects, it might not be necessary to promise any time reductions or savings in costs. This is due to a fact that if first takted projects ‘fail’, and the promised time reductions will not be achieved, the customer might not be eager to give allowance to utilize takt principles in future projects. It is more advisable to promise that the project or its sub-processes, such as structural design, will simply keep on the schedule. This allows one to have more buffers and acceptance for practicing the new methods in real life. When the new procedures and processes become familiar to designers, and project managers learn how to do takt planning and takt control, it is time for more high-performance promises.

In order to achieve lasting changes in organizational behavior, the culture and mindset of managers and employees must be shifted. For this reason, it would be advisable to first implement and adapt basic lean principles (culture) and only after that apply takt planning and other methods and tools. However, past experiences have taught that in order to change the culture and adapt new philosophies, there must also be something concrete. Otherwise the resistance gets too high. Thus, both the philosophy and methods should be developed and implemented simultaneously.

7. PROPOSAL FOR IMPROVEMENT

It seems like the gap between current situation and future vision, where the design process is based on a project-pulled takt plan and it flows smoothly without major interruptions, is too high. In order to get there, it is more reasonable to move forward with small and simple development steps rather than taking one huge leap and hope for the best.

Based on the two iteration cycles made both during and after the workshops, one last proposal for improvement was developed. This proposal is supposed to work as a baseline for the future target company's way to use and utilize takt planning in structural design processes. By means of demonstrating the proposal of improvement, the author developed an example of a takt plan for precast concrete element design process. Author's vision of this takt plan is illustrated in figure 19 and explained in detail in the following paragraphs.

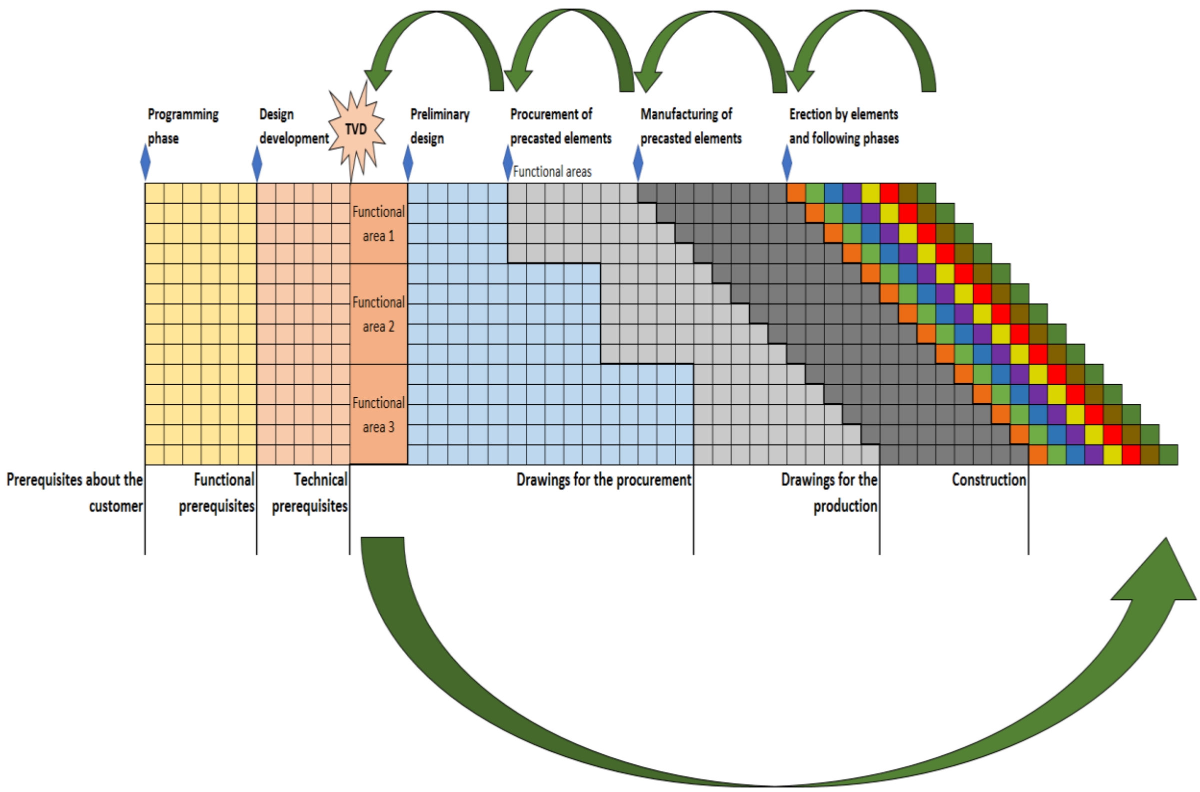

Figure 19. *The author's sketch of a project-pulled takt plan for precast concrete element design process.*

Programming and design development

In programming and design development phases, the emphasis is rather on the ideas of what should, could, and will be done, than in optimizing the productivity of labor in terms of time reduction or savings in money. Thus, these phases **do not need to be takted.** This can also be seen in figure 19. However, design development and programming phases can benefit from lean design principles, such as collaboration and transparency, to get the most of teamwork and brainstorming. The most essential goal in construction project's early phases is to create a positive environment of trust, and get rid of the 'culture of the accusing finger'.

The programming phase includes everything that happens before graphic design, e.g. feasibility studies and project planning. (Pennanen 2012) Although the spatial environment is defined in the programming phase, it can be realized in numerous ways and be based on many different design solutions. The purpose of the design development phase is to narrow down the number of these possibilities.

In the beginning of the design development phase, the building cannot yet be known as a physical object. (Pennanen 2012) During this phase, designers produce several sketches and preliminary estimates. Required prerequisites and degrees of accuracy for these sketches are defined **collaboratively.** Different functional areas and client's spatial area prioritization are also defined during design development. This is done according to the three-level method (macro level). The zoning into functional areas will work as a baseline for the takt planning of the construction production process, which in turn defines and governs the pull for designing and procuring the precast concrete elements.

Preliminary design, procurement, and manufacturing of the precast elements

The takt plan of the construction production process determines the pull for manufacturing, procurement, and design of the precast concrete elements. The pulling force of the production weakens the further away in time the project phase is. This means that the earlier the design task is, the rougher degree of accuracy it has. Thus, takted design entities are broad at early stages of a project, and become smaller and more accurate the further the project gets.

The procurement of precast concrete elements requires certain drawings with a specific degree of accuracy. These drawings do not need to be feasible yet, because prefabrication factory does not have to know every single detail in order to plan and prepare their own manufacturing process. However, in order to eliminate the waste of over processing, overproduction, and defects, it is important to define the appropriate degree of accuracy. This requires close cooperation between design, manufacturing and production, thus it must be done by using collaborative working methods.

The preliminary design should also take the functional areas and their prioritization into account (figures 8 and 12). Pull for that stems from the construction production.

Designers and design disciplines must be able to determine **what prerequisites** they need, **when** the prerequisites are needed, and **from where** to get them. Designers must be proactive, ask intelligent questions, and demand actions from others by means of well-adapted lean philosophy and relevant lean methods or tools, such as Kanban Board (figure 18). In other words, designers must know one's place in the project's value chain in order to have a clear picture of what to do, which prerequisites are required, when they must be delivered, and from where to look for them. By utilizing the principles of Big Room working or Knot working, designers can lower these barriers and share information more effectively.

A well-performed structural design and engineering commission requires good planning of own work, realistic schedules, and effective use of resources. Milestones and other sub-goals must be set as challenging but realistic. It must also be noted, that well-performed schedule planning becomes only partly beneficial if the monitoring and steering are lacking. Thus, in addition to good planning, a well-performed structural design and engineering commission requires also constant monitoring and proactive adjustment mechanisms (e.g. table 2). Kanban Boards (figure 18) can serve as transparent tools in the management of own commissions in terms of planning, scheduling, resourcing, monitoring, and adjusting the work contents and working methods.

Milestone-based approach can be very helpful when organizing different design activities and available resources into a logical sequence of design steps and phases. Thus, by cutting structural design and engineering commissions into smaller pieces, and planning the resourcing according these smaller designing entities, it is possible to get the best benefits from the milestone-based thinking. The milestones should be planned by taking the pull from the target dates of pre-defined design packages.

Specific design packages with specific degrees of accuracy must be delivered on specific dates. The closer the beginning of the production phase gets, the smaller and more accurate the design packages must be. This means that also the demand cycle for the design packages becomes shorter. Short and demanding pace (takt) for design packages requires both pull-planning from the construction production and lists for required design prerequisites. These prerequisites are illustrated underneath each interface in figure 19. The lists of required design prerequisites must be transparent and they should be created by using collaborative working methods (the three-level method, norm level).

The erection by elements and following work phases

The norm level's takt planning for the **construction production process** can be initiated immediately after the functional areas and their prioritization are determined in the design development phase. An early takt plan for production process enables production-pulled backwards planning and scheduling for manufacturing, procuring, and designing the precast concrete elements. Since the functional areas are known, the pull-planning can be done by taking the macro level's spatial prioritization into account.

The norm level's takt planning is done according to the three-level method's 12 steps of takt planning (figure 10). This is done by reflecting the client's requirements, e.g. spatial prioritization, building time, and spatial divisions defined at the macro level. By following these steps **collaboratively**, the project team can create a systematic and feasible takt plan. This takt plan will be supplemented and specified as the designing proceeds, the drawings become more accurate, and the working methods to be used become clear for all project parties.

Flexibility must be the core idea of a standardized building and design process. Thus, the micro level's daily management comes in on a project when the drawings become more feasible and actual production planning gets started. Micro level's daily management activities include weekly and daily takt meetings, short-cycled control, and proactive adjustments to the original takt plan that has been developed at the norm level.

Transition period from the current situation towards the future vision

Although the proposed way of implementing lean principles and takt planning to create a functional flow for the whole construction project is idealistically simple, there is still a long way to go before that kind of approach can be applied broadly and successfully. Traditional project systems and contracts are not favorable to new and innovative working methods and tools that emphasize collaboration and transparency. Thus, some transitional stages and small development steps are needed.

The first step is to develop a lean method and use it in teaching designers and applying lean principles in the target company's daily business. Another step on the way towards full implementation of takt planning could be, for instance, utilizing Kanban Boards for planning, scheduling, resourcing, monitoring, and managing the internal structural design and engineering commissions When basic lean principles have been widely adapted and the first drafts of takt planning methods are tested and piloted, it is time to implement takt planning broadly and as a more mature concept.

8. DISCUSSION

According to Linnik et al. (2013), Heinonen et al. (2016), Dlouhy et al. (2016), and many other researchers, recent experiments and studies have shown that takt planning can lead to significantly shorter lead times and schedules in construction production by creating steady streams of predictable and properly sequenced work across the defined geographic areas and appropriately planned working crews. However, structural design activities differ from construction production activities since unlike construction production, design is not a straightforward process. In construction production, the continuous flow emphasizes movements of people and material. In design, the focus is rather on making the information flow. This requires broad understanding of the project, and constant interaction and collaboration between different designers and design disciplines.

If the optimization activities are only made for individual construction phases and the information is given to the next phase over so-called ‘invisible walls’, a lot of information vanishes. Thus, all those who are specifically involved, should be able to ask questions about how other parties would like to perform their work, what resources or prerequisites they need, what kind of team sizes they favor, and in which sequence the activities should be carried out. This emphasizes collaborative working methods and transparency. If takt planning will be implemented in structural design or in any other design disciplines, the working methods must be collaborative and transparent. This concerns each project party equally.

Design processes are iterative by nature. Wasteful negative iteration can compose a significant proportional share of designers’ working time. Lack of collaboration in design creates waste too. Misspent time leaves less time for value-added design activities, which might result in poor design quality and several significant problems at the operational level. Negative iteration can be avoided by planning design processes comprehensively at an early stage, and by understanding the information flow between different design activities. This approach requires collaborative and effective teamwork as well as early definition of customer values and demands for the project.

According to Sacks (2004), a significant amount of project managers’ time might be wasted due to the uncertainty stemming from poor design solutions. One major reason for this is catenating construction project’s design and production as separate sequential phases. A high level of uncertainty means that even more information must be shared. Poorly managed information flow causes waste and unnecessary use of resources. The high level of uncertainty can be tackled by using collaborative project systems that enable effective utilization of expertise and knowledge of the project team’s participants to improve the information flow. In these project systems, design and production phases are usually overlapped.

There must also be close collaboration between design and production disciplines. This is needed because design process and its features are seemed to be poorly understood at construction site, and on the other way around, procurement and production processes are not very clear for designers. The less clearly-takted elements there are in a construction project, the more beneficial good teamwork and collaborative working can be.

According to Liker (2004) Continuous improvements require “an atmosphere of continuous learning and an environment that not only accepts, but actually embraces change”. The same way of thinking applies also to implementing lean methods and tools, such as takt planning, in structural design processes or in any other processes in the construction industry.

However, many things in both construction production and design happen in uncontrolled and chaotic environment. The dynamic nature of construction projects’ environment appears to be an easy excuse to base and justify one’s reluctance to change or adapt new working methods and philosophies. Thus, transparent, well-planned, and collaboratively developed schedules and methods are still rare in construction projects. Instead of that, desperate ‘firefighting’ is more common. Even more harmful for the continuous improving is the present culture, where these ‘firefighters’ are often seen as good managers and employees, although the ‘fires’ could be avoided with good planning, transparency, and collaborative working methods.

The know-how in new and innovative working methods, such as takt in production or flow in design, tend to be too much on individual early adapter’s shoulders. Because lean principles emphasize collaboration and optimized processes, all project team members and different disciplines in production and design should work together for a common goal where the project team’s common competence outnumbers the sum of its individuals’ competencies.

Basic lean principles are more general than takt principles and therefore it is easier to apply basic lean principles in structural design. The three-level method insists that the project-pulled takt planning in construction production stems from the customer demand. When this notion is considered from the perspective of structural design (or any other design discipline) the construction production itself can be considered as the customer. Thus, in order to achieve any benefits from a takted structural design process, the pull planning must stem from the construction production. This means that whether the structural design process itself is scheduled based on the takt or not, it must be aligned with the following working sequence, schedules, and priorities of the construction production. Otherwise the overall benefits will be of minor importance.

In construction production, different trades are usually highly specialized in one or few work activities. For instance, an electrician carry out electrical work and a painter paints. Structural design, however, is engineering consultancy where the designers are usually highly educated and one part of their professional expertise is the capability to design various structures all the way from the foundations to the ridge beams. In a takted construction production process, the Train of Works consists of wagons which are composed of one or more trades that usually represent different specialized sub-contractors. In structural design, such division into wagons would result in a situation where one designer would only design foundations for buildings while some other designer would specialize in precast concrete columns or hollow-core slabs. Even though this could be an efficient way to design, its psychological aspects would be far more negative because highly educated people, e.g. designers and engineers, usually want their work to be challenging and varied.

This Master's Thesis was part of the target company's broad Lean Development Project. The purpose of the Thesis was to study how takt planning has been used in manufacturing and construction production and, based on the findings, develop a first version of the concept where takt planning is implemented in the target company's structural design process and other lines of business.

More important than takting the processes in structural design and engineering commissions, is planning and managing own work well. This includes scheduling and resourcing the commission, daily management, and required adjustment mechanisms to achieve the goals. However, by implementing takt planning in construction production, it is possible to use backwards scheduling to extend the pull system to concern the previous phases too, and thus, takt the design processes as well. This means that the target company p's construction management commissions enable effective implementation of takt planning, not only in construction production, but also in design.

If takt planning is integrated into the project planning at an early stage, other design disciplines can also participate in project planning and commit to follow the lean principles and takt plan. Furthermore, if designers work collaboratively to understand the designing sequence, recognize dependencies, and make them transparent, it is possible to achieve a stable and continuous information flow where designers do not have to halt their work because some preceding information is missing. This approach is strongly related to Toyota's just-in-time delivery.

Figure 19 presents an exemplary solution for a project-pulled takt plan for precast concrete element design process. It illustrates a scenario where a takt plan of the construction production process determines the pull for manufacturing, procurement, and design of the precast concrete elements. The prerequisite information for production planning stems from the customer demands, and project's spatial division into functional areas defined in programming and design development phases. Short and more demanding pace for design packages require both pull-planning from the production and lists for required prerequisites. Both are illustrated in figure 19.

Although the framework of figure 19 is idealistically simple, traditional project systems and contracts are not favorable for new and innovative working methods and tools that emphasize collaboration and transparency. Thus, some transitional stages and small development steps are needed. These steps include adapting and applying basic lean principles in order to understand the role of lean philosophy, continuous flow, transparency, and collaboration in successful projects. The broader implementation of simpler lean tools, such as Kanban Board, Big Room, and Knot working, are low-threshold tools to adapt first on the way towards full implementation of takt planning in both construction production and design.

Figure 19 illustrates only one possible solution of how a takted structural design process could look like. In order to get the best results out of the target company's Lean Development Project, a greater number of potential solutions should be developed. This is due to the amount of different divisions within the target company. These divisions differ significantly from each other by nature. Thus, what works in one line of business may not work in some other line of business.

9. CONCLUSION

This study implies that takt planning can be implemented in structural design or in any other design process. However, this should not be done unconditionally, but rather by means of prerequisite demands, pull from the construction production, and project-pulled systems stemming from the customer demands.

Based on an overlying literature survey (chapters 2 and 3), the author acquired a comprehensive overall impression about lean and takt planning principles in manufacturing and construction. In addition to the knowledge gathered from the literature, the author did a study trip to Germany to acquire more comprehensive understanding about the doctrine developed in the Karlsruhe Institute of Technology (KIT), and see real-life examples of takted construction projects. This complementary knowledge and real-life projects facilitated the understanding of the literature written by the researchers from the KIT (chapter 4).

After the study trip, the author analyzed how takt planning could be implemented in design processes (chapter 5). The author designed and conducted two workshops of how, and in which format, takt planning could be applied into usable concepts at the target company, and based on the findings, designed and conducted a third workshop where the objective was to summarize everything that has been learned so far, figure out what are the most relevant problems to tackle, what are the methods and tools for that, and how to implement, test, and further develop them (chapter 6).

Based on everything described above, a final proposal for improvement was developed (chapter 7). This proposal is supposed to work as a baseline for implementing takt planning in structural design processes and performing all required transitional steps on the way there. Hence, the objective of the study has been met within the appropriate limits for a Master's Thesis.

However, to get the best results out of the target company's Lean Development Project, more potential solutions should be developed, tested, redesigned, and piloted. The proposal for improvement was developed for takting a precast concrete element design process. Although the principles illustrated in figure 19 and explained in detail in chapter 7 can be applied to other design disciplines or lines of business of the target company, some iteration and redesign must be performed. For this reason, the development work should continue and the other lines of business should also be covered.

One of the most important lessons of the Thesis is, that by takting a product, one can master only certain products, but by takting a process, one can master any kind of products. This is a fundamental finding for the future when takt is implemented more broadly in structural design or in any other design processes. Process perspective is more agile than product perspective and it enables more efficient use of collaborative and transparent working methods. The shift from seeing construction projects as seldom repeated and highly unique to understanding the possibility, that from the process perspective similarities could be recognized in greater detail, should be supported and enhanced. Thus, the differences between product and process perspectives in construction projects should also be further studied, and a future research about the shift would be beneficial for the whole construction industry as well as for traditional manufacturing.

The distribution between structural design and engineering commissions and construction management commissions clearly resonates with the target company's executives. Takting the design process and making it flow gained broad acceptance. However, the actual implementation of takt planning was considered as challenging. According to the workshops, right now the most essential goal is to enhance the organizational culture to fully understand the benefits of the lean philosophy, especially the importance of steady and continuous process flow. This opinion goes along with the author's observations and proposals.

Another key objective in the future is to determine required prerequisites at an early stage of projects, and encourage project managers and designers to proactively identify what prerequisites they need, when the prerequisites are needed, and from where to get them. Although prerequisites vary depending on the project, the number of different project types is not too high for creating a standardized methods and tools to manage the prerequisites. The management of the prerequisite conditions and requirements is a significant challenge throughout the whole construction industry. Thus, it requires further studies and would be highly useful subject matter for a follow-up research.

REFERENCES

Literature references

Abdelhadi, A. (2016) Using Lean Manufacturing as Service Quality Benchmark Evaluation Measure. Emerald Group Publishing Limited Bingley, UK, vol 7, pp. 25-34.

Ballard, G. (1998). Positive vs Negative Iteration in Design, Proceedings of the 8th Annual Conference of the International Group for Lean Construction, Brighton, UK, July, 1998.

Ballard, G., Harper, N., & Zabelle, T. (2003) Learning to See Work Flow: Application of Lean Production Concepts to Precast Concrete Fabrication. Journal of Engineering, Construction and Architectural Management, 10(1). Blackwell Publishers, Oxford, U.K. pp. 6-14.

Ballard, G., & Howell, G. (1994) Implementing Lean Construction: Stabilizing Work Flow. Proceedings of the 2nd Annual Meeting of the International Group for Lean Construction, Pontificia Universidad Catolica de Chile, Santiago, September 1994. Pp 101-110.

Ballard, G., & Howell, G. (2003) Lean project Management. Building Research and Information, 31(2), pp.119-133.

Binninger, M., Dlouhy, J., & Haghsheno, S. (2017a). Technical Takt Planning and Takt Control in Construction. LC3 2017 Volume II – Proceedings of the 25th Annual Conference of the International Group for Lean Construction (IGLC). Walsh, K., Sacks, R., Brilakis, I. (eds.), Heraklion, Greece, pp. 605–612. DOI: https://doi.org/10.24928/2017/0297.

Binninger, M., Dlouhy, J., Steuer, D., & Haghsheno, S. (2017b). Adjustment Mechanisms for Demand-oriented Optimisation in Takt Planning and Takt Control. LC3 2017 Volume II – Proceedings of the 25th Annual Conference of the International Group for Lean Construction (IGLC). Walsh, K., Sacks, R., Brilakis, I. (eds.), Heraklion, Greece, pp. 613–620. DOI: https://doi.org/10.24928/2017/0086.

Design Council. Design Methods for Developing Services. Available at: https://www.designcouncil.org.uk/sites/default/files/asset/document/Design%20methods%20for%20developing%20services.pdf.

Dlouhy, J., Binninger, M., Oprach, S., & Haghsheno, S. (2016). Three-Level Method of Takt Planning and Takt Control – A New Approach for Designing Production System in Construction. Proceedings of the 24th Annual Conference of the International Group for Lean Construction, Boston, MA, USA, sect.2 pp. 13–22. Available at: <www.iglc.net>.

Ehrlenspiel, K. (1999). Planung und Kontrolle Integrativer Produktentwicklung. Springer Fachmedien Wiesbaden GmbH, 107.

Emdanat, S., Meeli, L., & Christian, D. (2016) A Framework for Integrating Takt Planning, Last Planner System and Labor Tracking. Proceedings of the 24th Annual Conference of the International Group for Lean Construction, Boston, MA, USA, sect.2 pp. 53–62. Available at: <www.iglc.net>.

Fiallo, M., & Howell, C. (2012) Using Production System Design and Takt Time to Improve Project Performance. Proceedings of the 20th Annual Conference of the International Group for Lean Construction. San Diego, USA.

Frandson, A., Berghede, K., & Tommelein, I. (2013). Takt-time planning for construction of exterior cladding. Proceedings of the 21st Annual Conference of the International Group for Lean Construction. Lima, Peru.

Frandson, A., Berghede, K., & Tommelein, I. (2014). Takt-Time Planning and the Last Planner Proceedings of the 22nd Annual Conference of the International Group for Lean Construction. Oslo, Norway.

Frandson, A., Seppänen, O., & Tommelein, I. (2015) Comparison between location based management and Takt Time Planning. Proceedings of the 23rd Annual Conference of the International Group for Lean Construction, 28-31 July, Perth, Australia, pp. 3-12, Available at www.iglc.net.

Frandson, A., & Tommelein, I. (2014) Development of a takt-time plan: A case study. Proceedings of the Construction Research Congress, Atlanta, GA, May.

Haghsheno, S., Binninger, M., Dlouhy, J. & Sterlike, S. (2016). History and Theoretical Foundations of Takt Planning and Takt Control. Proceedings of the 24th Annual Conference of the International Group for Lean Construction, Boston, MA, USA, sect.1 pp. 53–62. Available at: <www.iglc.net>.

Hamzeh, F. R., Ballard, G., & Tommelein, I. D. (2008). Improving construction work flow – The connective role of lookahead planning”. Proceedings of the 16th Annual Conference of the International Group for Lean Construction. Manchester, UK.

Heinonen, A., & Seppänen, O. (2016). Takt Time Planning: Lessons for Construction Industry from a Cruise Ship Cabin Refurbishment Case Study In: Proceedings of the 24th Annual Conference of the International Group for Lean Construction, Boston, MA, USA, sect.2 pp. 23–32. Available at: <www.iglc.net>.

Hopp, W. J., & Spearman M. L. (2008) Factory Physics. Shop Floor Control, Waveland Press, Long Grove, IL, 95.

Huovinen, P. (2018) Introduction to Global Capital Investment Markets (CIMs) as Focal Contexts. RAK-59126 Management in International Construction Business (MGTICB) Spring 2018 – File 8.

Kalsaas, B.T., Skaar, J. & Thorstensen, R.T. (2015) Pull vs. push in construction work informed by Last Planner. Proceedings of the 23rd Annual Conference of the International Group for Lean Construction. Perth. Australia, pp. 103-112, available at www.iglc.net.

Kenley, R., & Seppänen, O. (2009). Location-based management of construction projects: Part of a new typology for project scheduling methodologies. In (Ed.), Winter Simulation Conference M. D. Rossetti, R. R. Hill, B. Johansson, A. Dunkin and R. G. Ingalls, eds.

Kenley, R., & Seppänen, O. (2010). Location-based Management for Construction Planning, scheduling and control. Spon Press. London and New York.

Kerosuo, H., Mäki, T., & Korpela, J. (2013). Knotworking-A novel BIM-based collaboration practice in building design projects, Proceedings of the 5th International Conference on Construction Engineering and Project Management ICCEPM, 9-11, January 2013.

Keskiniva, K., Junnonen, J-M., & Saari, A. (2018). Virtauttamisen toteutuksen periaatteet ja soveltamismahdollisuudet rakennushankkeissa: Rain-tutkimushankkeen osaraportti 1. Tampereen teknillinen yliopisto. Rakennustekniikan laboratorio. Rakennustuotanto ja -talous. Raportti; Vuosikerta 23.

Kivistö, G., & Ohlsson, H. (2013). Expanding Lean into Transportation Infrastructure Construction, Master of Science Thesis in the Quality and Operations Management Programme.

Koskela, L. (2000). An Exploration Towards a Production Theory And Its Application to Construction. Construction Management Production Design Theory Utilization Thesis. Available at: http://urn.fi/urn:nbn:fi:tkk-001187.

Koskela, L., Bølviken, T., & Rooke, J. (2013). Which are the wastes of construction? Proceedings of the 21st Annual Conference of the International Group for Lean Construction. pp. 3 – 12.

Koskela, L., & Koskenvesa, A. (2003). Last Planner -tuotannonohjaus rakennustyömaalla, VTT Tiedotteita 2197, VTT, Espoo, 106 p.

Lean Production Expert (2012). “Taktzeitdiagramm [Takt time diagram].” Online verfügbar unter http://www.lean-production-expert.de/lean-production/taktzeitdiagramm.html.

Liker, J. (2004) The Toyota Way: 14 Management Principles from The World’s Greatest Manufacturer. McGraw-Hill Global Education Holdings, LLC.

Liker, J. (2006). Las Claves del éxito de Toyota (The Toyota Way). Barcelona: Gestión 2000.

Lindgren, M. (2016). Suunnittelun virtauttaminen, 8.12.2016, LCI Finland, Helsinki, pp. 26.

Linnik, M., Berghede, K., & Ballard, G. (2013). An Experiment in Takt Time Planning Applied to Non-Repetitive Work. Proceedings of the IGLC-21, July 2013, Fortaleza, Brazil, 609-618.

Mahesh, K. S. (2016). Management & Entrepreneurship. Lecture. Department of IE & M. JSS Academy of Technical Education. Bengaluru. Available: http://slideplayer.com/slide/11118441/.

Mariz, R. N., Picchi, F. A., Granja, A. D., & de Melo, R. S. S. (2012) A Review of the Standardized Work Application in Construction. Proceedings of the 20th Annual Conference of the International Group for Lean Construction. San Diego, USA.

Mitropoulos, P., & Howell, G.A. (2002). Renovation projects: Design process problems and improvement mechanisms, Journal of Management in Engineering, Vol. 18(4), pp. 179 – 185.

Ohno, T. (1988), Toyota Production System: Beyond Large-Scale Production, Productivity Press, Portland, OR.

Pennanen, A. (2012) Talonrakennushankkeen hallinta ohjelmointi- ja suunnitteluvaiheessa (The management of a building construction project in the programming and design phases). Adjunct Professor Ari Pennanen’s Lecture Material. Tampere University of Technology, The Faculty of Built Environment. Available only in Finnish.

RT 10-11128. 2013. Rakennesuunnittelun tehtäväluettelo RAK12. RT Instruction Card. Confederation of Finnish Construction Industries RT.

Sacks, R. (2014). BIM and Lean Construction - Can BIM Remove Waste from Construction Processes? Tekla European BIM Forum 2014, 13.-14.2.2014, Berlin, pp. 66.

Scott, W. R., & Davis, G. F. (2007). Organizations and Organizing: Rational, Natural and Open systems perspectives. New Jersey: Pearson Prentice Hall.

Seppänen, O. (2014) A Comparison of Takt Time and LBMS Planning Methods. Proceedings of the IGLC-22, June 2014. Oslo, Norway.

Soto, L. (2007). Construction Design as a Process for Flow: Applying Lean Principles to Construction Design, Master of Science, Massachusetts institute of Technology.

Tommelein, I. D. (2017) Collaborative Takt Time Planning of Non-Repetitive Work. LC3 2017 Volume II – Proceedings of the 25th Annual Conference of the International Group for Lean Construction (IGLC). Walsh K., Sacks R. & Brilakis I. Heraklion, Greece, pp 745-752. DOI: https://doi.org/10.24928/2017/0271

Vatne, M. E., & Drevland, F. (2016). Practical Benefits of Using Takt Time Planning: A Case Study. Proceedings of the 24th Annual Conference of the International Group for Lean Construction, Boston, MA, USA, sect.6 pp. 173–182. Available at: <www.iglc.net>.

Willis, C., & Friedman, D. (1998). Building the Empire State Building, W.W. Norton & Company, New York.

Womack, J. P., Jones, D. T., & Roos, D. (1991) The Machine That Changed the World: The Story of Lean Production. Harper Perennial. November 1991.

Womack, J. P., & Jones, D. T. (1996) Lean Thinking: Banish Waste and Create Wealth in Your Corporation. Productivity Press, First Edition. August 1996.

Yassine T., Bacha M. B. S., Fayek F., & Hamzeh F. (2014) Implementing Takt-time Planning in Construction to Improve Work Flow. Proceedings of the IGLC-22, June 2014. Oslo, Norway

Private discussions

Dlouhy, J., & Binninger, M. (2018) private discussions between 23rd April and 3rd May, 2018. Munich and Rastatt, Germany.

Suunnitteluprosessin kehittäminen – Diplomityö

1. Perustiedot; Nimi, yksikkö, työnkuva.
2. Kuvaile lyhyesti (esim. ranskalaisin viivoin) tyypillistä suunnitteluprosessia / työnkuvaasi suunnitteluprosessissa.
3. Missä osissa A-Insinöörien suunnitteluprosessia mielestäsi / kokemustesi perusteella esiintyy eniten ja suurimpia ongelmia ja haasteita? Toisin sanon, mikä nykyisessä toimintatavassa mättää?
4. Millä tavalla ongelmat ja haasteet ilmenevät?
5. Miten ja mihin asioihin ko. asiat vaikuttavat?
6. Mitä ja miten omasta mielestäsi nykyisiä menetelmiä ja toimintatapoja pitäisi/voisi parantaa?
7. Mitkä lähtötiedot ja niiden puutteet ovat aiheuttaneet / aiheuttavat tyypillisesti ongelmia?